Limnology of Tasmanian Freshwater Coastal Dune Lakes with particular reference to the microcrustacea

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DECLARATION

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ABSTRACT

Limnologically the dune lagoons of Tasmania are similar in character to other temperate mainland Australian dune lakes. They are of low-moderate salinity, moderate to high dystrophy and have a seawater ionic dominance Seasonal limnological character of dune lakes is dependent upon the seasonal water level fluctuations in individual lagoons and basin morphometry. The degree/magnitude of these fluctuations is influenced by the timing and volume of winter rains, and the length and severity of the summer Shorelines are therefore often indefinite with exposure and reinundation of the littoral shallows.

The microcrustacean faunal diversity of these dune lakes is dependent upon the 'stability' of the individual lagoon. Well vegetated, shallow lagoons with extensive areas of submerged and emergent aquatic macrophytes tend to have significantly higher species diversity. In contrast dune lakes which have relatively large areas of open water, which are deep relative to surface area and which have less aquatic macrophyte vegetation, have significantly reduced species diversity. Seasonal drying and reinundation of the littoral shallows of astatic and ephemeral lagoons also contribute to habitat spatial heterogeneity and thus species diversity.

The shallow, dystrophic coastal dune lakes of Tasmania with extensive littoral emergent and submergent aquatic macrophyte communities, subject to seasonally variable water levels are more biologically diverse than the relatively depauperate inland lakes.

This study has demonstrated that the coastal dune lakes of Tasmania, based on their mode of origin, age, limnology and microcrustacean faunal assemblages, differ from the inland alpine lakes and wetlands of the island. The freshwater coastal dune lakes form a third limnological province in Tasmania.

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CHAPTER 1
INTRODUCTION: LIMNOLOGICAL CHARACTERISTICS OF COASTAL DUNE LAKES.

1.1 INTRODUCTION

Tasmania is an island about 67,000 km^2 in area lying between latitude 40°30'S and 44°S and longitude 144°30'E and 148°30'E (**Figure** 1.1). Physically Tasmania is part of the Eastern Australian Highlands, but separated from south-eastern Australia by Bass Strait, a shallow marine transgression over 240 km wide and between 40-85m deep. There are numerous offshore islands, some relatively large. A chain of island groups occurs on the eastern side of Bass Strait, including the Furneaux, Kent and Hogan groups. On the western side, there are very few small islands; King Island is situated about half way between Cape Grim (north west Tasmania) and Cape Otway (Victoria). Bruny, Maria and Schouten are larger islands off the east coast, separated by shallow water from mainland Tasmania.

Topographically the main island of Tasmania is mountainous, and the coastal plains are generally narrow, except in the north and north-east Tasmania has a temperate maritime climate There is a strong precipitation gradient decreasing west to east across the island. Average annual rainfall varies from 3600 mm in the west to 550 mm in the east.

Tasmania's diverse topography and rainfall combine to offer a wide variety of natural water bodies. Lentic waters range from highland and lowland lakes (mostly glacial in origin) to swamps and coastal dune lakes and wetlands of both a temporary and permanent nature. The limnological character of Tasmania's inland lakes has been well studied (Buckney & Tyler 1973a,b, Croome & Tyler 1972, 1973, 1975, Steane 1979; Bowling *et al.* 1986; Bowling 1988; Tyler 1992). The island has a broadly based edaphic divide, running north-south, based largely on geology, vegetation, soils, and rainfall. As standing bodies of water reflect the geochemical, edaphic and vegetational characteristics of their catchments, there is a broadly based limnological discontinuity that largely follows the edaphic divide. This effectively separates the island into two distinct limnological provinces (Ling *et al.* 1989; Tyler 1992). The Eastern limnological province possesses a green underwater light climate, is oligotrophic, is located on Jurassic dolerite with a catchment of sclerophyllous woodland. The western limnological province possesses a red underwater light climate, dystrophic humic waters, and is located on button grass moors. Several authors (Neboiss 1977; Swain *et al.* 1977; Smith & Kershaw 1981; Shiel *et al.* 1989, Fulton 1982, 1990) found that the aquatic biota of Tasmania could also be separated into biogeographical provinces For example, the microcrustacean zooplankton of natural inland lakes is typically monospecific, usually a calanoid copepod species, with different species in the two limnological provinces. *Calamoecia tasmanica tasmanica*, or *Boeckella propinqua longisetosa* are found in the Western Province, whereas *Boeckella rubra* or *Calamoecia gibbosa gibbosa* are found in the natural lakes of the eastern province. In disturbed waterbodies of the same province *Boeckella symmetrica* or *Boeckella triarticulata* are found (Walsh 1991)

Lentic freshwater bodies in the narrow coastal margins of Tasmania have been less thoroughly investigated than highland lakes. A third limnological province within Tasmania has been suggested, based on biological and limnological parameters (Bowling 1988; Bowling *et al.* 1993, Shiel *et al.* 1989; Walsh 1991). Similarities exist in the age, origin and formation of the waterbodies within this province (Walsh 1991).

Significant proportions of the narrow sandy coastal lowlands which fringe Tasmania contain freshwater dune lakes and associated wetlands. Many of these are perched above the general water table, in dune hollows created by wind action and sealed by organically-cemented sand. Others are

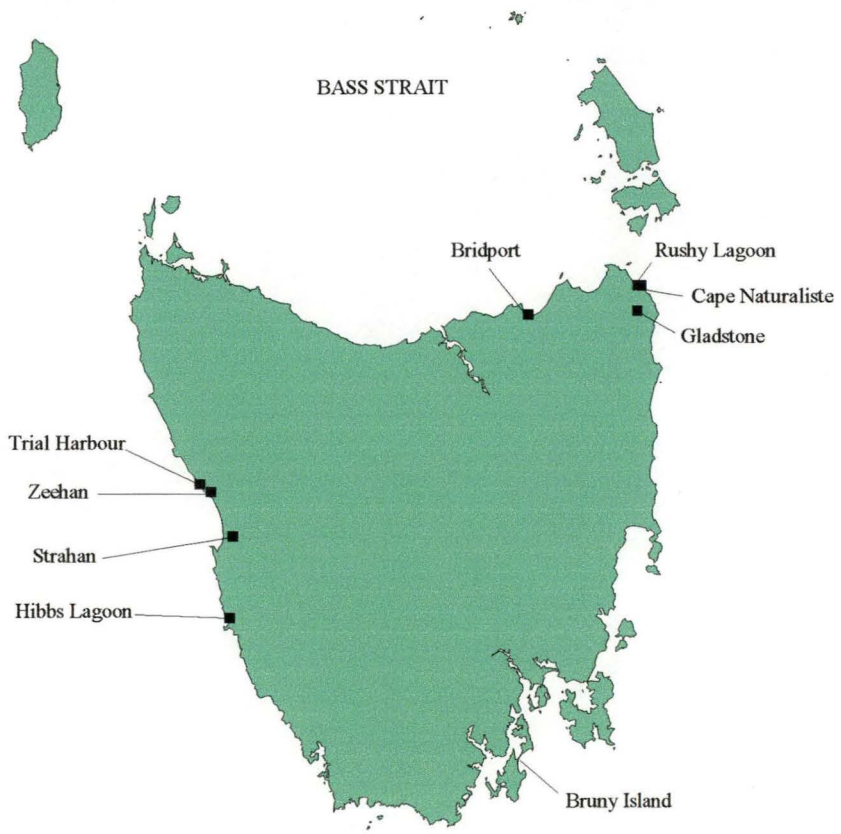


Figure 1.1 The island of Tasmania, with key reference points indicated.

surface expressions of the ground water table or shallow waterbodies impounded behind frontal dunes. Information on the coastal lakes, Tasmania's third limnological province (Croome & Tyler 1987; 1988), has been reviewed by Bowling (1988), Bowling *et al.* (1993) and Walsh (1991).

Limnological investigation of these water bodies show most to have an ionic composition dominated by Na^+ and Cl^-, and to be characterised by humic waters of low pH (Bowling 1988). In contrast to the dune lakes of mainland Australia (Timms 1986a), the Tasmanian dune lakes are species rich and diverse of microfauna and microflora, many of which are unique to these habitats, rare and/or endemic. (Koste & Shiel 1987; Shiel *et al.* 1989; Tyler 1992, 1996; Walsh 1991). Generally, the microcrustacean zooplankton community is dominated by *Calamoecia tasmanica tasmanica* or *Calamoecia gibbosa gibbosa* (Bayly 1961, 1964a, 1979; Bayly *et al.* 1975, Baharuddin 1978; Walsh 1991).

Many coastal lowland areas of eastern mainland Australia are fringed by plains of unconsolidated sands and siliceous dunes resulting from quaternary geomorphological events, cover extensive regions of these areas (Coaldrake 1961) These dune systems often contain small freshwater lakes and wetlands whose origins have been broadly classified by Timms (1982, 1986a, 1992). The term,'coastal lagoon', can have precise meaning (Barnes 1989), though Bowling *et al.* (1993) and Timms (1992) referred to all types of freshwater dune lakes in Australia as coastal lagoons. The latter practice is adopted in this study of Tasmania

To date, research on coastal freshwater dune lakes has concentrated on short term studies, often based on a single visit. Bowling *et al* (1992) believed that a lagoon found to be acidic and dystrophic on the first visit would remain so. However many coastal lagoons are ephemeral, or at least extremely variable in depth The majority are shallow, so small changes in depth are matched with relatively large changes in surface area and volume The physicochemical character of individual lagoons is therefore diurnally and seasonally variable (Walker & Tyler 1984; Townley *et al.* 1993; Froend *et al.* 1993; Balla & Davis 1993, Davis *et al.* 1993; Walsh *et al.* 1995)

In comparison to Tasmania, the coastal lakes of the Australian mainland, especially those of south-eastern Queensland and north-eastern New South Wales, have been more comprehensively studied, and exemplify the limnology of this type of waterbody Most are located in the siliceous coastal areas in south-east Queensland. The most numerous and best examples are located on Fraser Island, which has more sizeable lakes per unit area than anywhere else in Queensland (Bayly 1966).

Many of the Queensland lakes are of the perched dune lake type, however a few represent watertable windows (Bayly 1964a). The New South Wales lakes are of a more diverse formation. Water colour varies from clear and highly transparent in some lakes, especially the frontal dune ponds, to humic and strongly attenuating in perched dune lakes (Timms 1982; Bayly 1964a; Bayly *et al.* 1975). However, other than Secchi disc measurements, the optics of these lakes have been little studied. Water transparencies, measured by Secchi disc, range from 0.35 to 8 20 metres (Bowling 1988). Most of the lakes are polymictic, without thermal, oxygen, or chemical stratification (Timms 1969; Bayly *et al.* 1975).

The freshwater coastal lakes of Queensland are a homogenous group with respect to water chemistry (Bowling, 1988). All are dilute, with an average salinity of about 40 mg/l, with sodium and chloride contributing almost 80% of the dissolved ions, although altitude and distance from the coast may cause variations (Bayly 1964a; 1984; Little & Roberts 1986, Timms 1986b; Bowling 1988). The atmospheric supply of ions from the sea is a major influence on lake water chemistry,

especially as the lakes lie on deep siliceous sands, so that the supply of ions by weathering processes is negligible (Bayly 1964a; Little & Roberts 1986). The silica content of Fraser Island lake waters is low, suggesting that their waters are derived mainly from local rainwater rather than from groundwater sources. This may be due to the lakes draining slowly but continuously into the main underground water body, thus maintaining their low salinities (Little & Roberts 1986) Bowling (1988) suggests that this is also possibly true for some Tasmanian coastal lagoons.

The coastal dune lakes of north-east New South Wales are typically oligotrophic (chlorophyll a values <9 μg/l) and more variable in their physico-chemical characteristics, due to their different types of formation. Some are humic, acidic, and of low salinity, with ionic compositions strongly dominated by sodium and chloride. Others have higher conductivities, are less coloured and less acidic, and have calcium and bicarbonate as their major ions (Bayly 1964a; Timms 1982).

The pH values of Queensland coastal lakes are generally below 6.0 (Bayly 1964a; Little & Roberts 1986, Timms 1986b; Bayly & Williams 1972). Coloured organic acids are the principal determinants of pH. Lakes with a pH greater than 5.0 are usually colourless, while those of less than 5.0 are humic, with pH decreasing as humus concentration increases. The pH values of New South Wales coastal lakes vary considerably, but the larger ones tend to be acidic (Timms 1982).

A number of biological studies has been undertaken on Queensland and New South Wales coastal lakes. The main component of the zooplankton is usually the copepod *Calamoecia tasmanica tasmanica* which has its highest population densities in the most humic lakes Other planktonic animals are less common, but the lakes have a richer and more diversified littoral invertebrate fauna Emergent plants are also common around the shorelines (Timms 1982; Bayly 1964a).

Victorian freshwater coastal lakes are also of diverse origins (Timms 1973, 1977). This heterogeneity is clearly evident in their chemical features. Many in Gippsland show some dystrophy, are slightly acid, and dominated by sodium and chloride; a few are alkaline and enriched with alkaline earth bicarbonates (Timms 1973) Those of the Portland region are alkaline, due to enrichment with calcium and bicarbonate, and have clear, transparent waters (Timms 1977).

Coastal lakes in South Australia differ from those of the eastern Australian coastline in that many are markedly saline, with salinities ranging from about half to ten times that of seawater. Sodium and chloride are the dominant ions, and pH values are above 7.0 (Bayly & Williams 1966; Bayly 1970).

It appears that freshwater coastal lakes in West Australia may differ considerably from their eastern Australian counterparts (Bowling 1988). The wetlands of the Swan Coastal Plain (south-west Western Australia) have been the subject of an extensive limnological and biological study (Townley *et al.* 1993; Froend *et al.* 1993, Balla & Davis 1993; Davis *et al.* 1993). This was the first comprehensive study of the physical, chemical and biological attributes of a large group of coastal wetlands in Australia and one of only several world wide. The majority of lagoons were alkaline and carbonate-enriched, reflecting the fact that many are located on a limestone formation A number of lagoons also displayed sulphate enrichment, with $SO_4 > Cl$ Coloured lagoons had pH values greater than 7. The majority of the lagoons were fresh to slightly saline. Many were nutrient-enriched, affected by agriculture and urban development, with up to one third of the lagoons classified as eutrophic. Seasonality of lagoons was an important factor determining invertebrate faunal composition of a lagoon. The fauna of permanent and seasonal wetlands was generally more

similar within these categories than between them. Biological investigations highlighted the importance of aquatic macrophytes in promoting species diversity. Seasonal monitoring showed higher microfaunal species diversity in seasonal lagoons compared to permanent lagoons

Many of Australia's coastal lagoons are under threat and many have been lost The great majority of Australia's population (80%) lives in the coastal margins. Since European settlement, the majority of coastal wetlands, dune lakes and lagoons have been converted to other uses such as urban development and agriculture. Of those remaining many are becoming badly degraded from such practises as indiscriminate clearing, stock grazing, cropping, tipping of refuse, extracting of gravel, sand mining, and run-off from pesticides, fertilisers, herbicides, and industrial wastes Coastal Wetland losses include:

Swan Coastal Plain, Western Australia - 75% (Riggert 1974)
coastal region New South Wales - 75% (Goodrick 1974)
coastal wetlands of south east South Australia - 89% (Jones 1978)
coastal plain of North East Tasmania (Steane 1992)

In contrast to the detailed biological studies of the Swan Coastal Plain, previous work on the freshwater microfauna and flora of Tasmania has been spasmodic, piecemeal and disjointed in that it has followed the interests of individual researchers. What is known is often based on a single visit or an ad hoc sampling regime where individuals have made the most of an opportunity to grab a sample when visiting the lagoons for other purposes. Timms (1987) investigated aquatic micro-crustaceans in a brief visit to Tasmania. He found several new and rare species, and concluded that much more research is warranted. Koste and Shiel (1986, 1987), Shiel and Tan (1990), investigating the rotifer fauna, concluded that the coastal dune lakes of Ocean Beach on the west coast of Tasmania are the richest in species diversity yet recorded from Australia. The authors suggested that this is the result of a long and undisturbed evolutionary history. Tyler (1992), Bowling *et al.* (1992) and Ling *et al.* (1989) have found new, unique and endemic algae in many of these coastal lagoons. A comprehensive limnological survey (a total of 323 individual water bodies sampled) of a key group in the Tasmanian aquatic micro-crustacean assemblage (Calanoida: Centropagidae) showed that many species (some endemic to Tasmania) are restricted in distribution and some only to coastal lagoons (Walsh 1991).

To the best of the authors knowledge there have been few previous studies in Tasmania concentrating upon aquatic microcrustacea and this study is one of only several that have dealt with Tasmanian aquatic microfauna. Previous studies have been piecemeal with data often extrapolated from single samples. There has been almost no work completed on seasonal dynamics or species assemblages.

Tasmania has lost substantial numbers of wetlands and lakes in coastal areas (Kirkpatrick & Tyler 1987; Steane 1992), particularly in the northeast coastal plain of the island This flat, low-lying sandy coastal plain, extending in places up to ten kilometres inland, contained a complex of interdigitating wetlands, most located close behind and impounded by great barriers of coastal sand dunes. These included lagoons, marshes and swamps with plant communities ranging from floating and submerged macrophytes in open lagoons to paper bark swamps, sedgelands and herbfields.

Many have been cleared and drained following World War II in the Soldier Settlement Scheme of the 1940-50's (Steane 1992). Another significant cause of loss was agricultural practices at the

time It is thought that up until then most of the dune systems were relatively vegetated and stable (Steane 1992) With agriculture and land clearing the dune systems became mobile, migrating inland, and a large number of lagoons and associated wetlands were obliterated or greatly diminished in size. Some have been bodily pushed inland (eastwards) by the sand. The few lentic wetlands that exist today between Bridport and Cape Portland "are a sorry remnant of the extensive and beautiful wetlands of fifty years ago" as a result of dune migration over the last 35 years (Steane 1992).

On the east coast increasing demand for urban and shack development at popular coastal beach resorts, for camping facilities and for recreational use, have also had deleterious effects.

There is increasing recognition of the importance of wetland ecosystems and of the threats posed to them. Wetland inventories are required to provide a basis for effective conservation and management. Information is needed in the distribution of, and extent of inundated areas, and, for ephemeral wetlands, on water regime (period and frequency of inundation). Data on the distribution of plant and faunal communities are needed to evaluate and select wetlands or groups of wetlands for management and conservation. The development of such inventories in Australia is sadly lacking

Microcrustaceans (copepods, cladocera and ostrocods) are vital links in Australian inland aquatic food webs as intermediate grazers between algae/bacteria and higher order consumers, eg macroinvertebrates and fish. Knowledge of their ecology in Australia is sadly lacking due in part to lack of suitable taxonomic references or expertise (Green & Shiel 1992). Biological surveys of this faunal group in Australia (particularly the cladocerans) have been few (Walsh 1991; Balla & Davis 1993; Davis *et al.* 1993).

1.2 AIMS

Coastal freshwater lagoons from several localities around the Tasmanian mainland and the Bass Strait Islands were investigated as an holistic study of the limnology and microcrustacean ecology of this relatively neglected group of waterbodies

The main objectives of this study are:

- to describe the microcrustacean fauna of freshwater coastal dune lakes from Tasmania and offshore islands.
- to investigate the physicochemical limnology of permanent, markedly astatic and ephemeral lagoons.
- to investigate the role of permanent and seasonal lagoons in supporting different microcrustacean species/communities
- to determine biogeographical relationships in the microcrustacean fauna of Tasmania, Bass Strait Islands and SE Australia.
- to investigate life history and ecology of dominant species.
- the classification of microcrustacean species into feeding groups by investigation of diet and feeding regimes to determine trophic relationships within these lagoons

Combined, this information would be expected to add further evidence for the argument of a third limnological province in Tasmania, and also provide baseline data for the management of fauna, water quantity and quality for wetlands within Tasmania.

CHAPTER 2
METHODOLOGY.

2.1 SAMPLE COLLECTING.

Two sampling regimes were used in this study. Biological and physicochemical samples were collected at approximately three to four month intervals between August 1991 and September 1992 from twenty wetlands between Cape Naturaliste and the township of Bridport in the NE of Tasmania. This was mainly to provide an indication of the gross variation among the wetlands, largely covering a range of wetland types over the study area. This broad scale approach gave an indication of the gross seasonal changes and some indication of annual variability. This approach was essential to meet the objectives of this study, the classification of lagoons on the basis of their biota and physicochemical characteristics.

However, a more intensive sampling regime and/or experimental studies were required for a greater understanding of the dynamic processes occurring in a particular wetland. Cladocerans and copepods have short life spans, particularly during the warmer summer months, and hence fortnightly or monthly sampling would more accurately describe species assemblages and population dynamics. Therefore results of this study should be considered to be broad outlines only Furthermore zooplankton populations are neither uniformly nor randomly distributed in a temporal or spatial sense (Hutchinson, 1967), therefore difficulties arise in obtaining representative samples from a body of water. A phenomenon known as zooplankton patchiness may occur in the horizontal plane whereas vertical migration may cause zooplankton to accumulate at particular depths.

A more intensive sampling program is essential to the understanding of the seasonal and long term changes in individual lagoons. Therefore, based on the above reconnaissance, six lagoons were selected for more intensive sampling. One of these lagoons (Cape Naturaliste No. 2) was abandoned not long into the study due to problems in accessibility The remaining five NE lagoons were sampled every four to five weeks between November 1993 to October 1994.

The two sampling regimes are essentially complimentary; the broad scale approach identifies the range of variation between lagoons and allows their categorisation; the intensive sampling allows a more detailed interpretation.

On the west coast of Tasmania, west of the township of Strahan, between May 1991 and November 1994, eight natural lagoons and two artificial coastal fresh waterbodies were sampled on ten occasions.

The Bass Strait Islands were sampled only once due to constraints in logistics, finance and facilities Twenty lagoons on King Island were sampled for biological and physicochemical values in December 1991. Sixteen lagoons from three islands of the Furneaux Group were sampled in February 1993. A complete physicochemical data set was not obtained for Flinders, Cape Barren and Clarke Islands due to the loss, misplacement and late arrival of sampling and survey equipment by the freight carrier.

The five Bruny Island lagoons were sampled several times during the period 1988-1992 Unpublished information for 1977 was obtained from Baharudin (1978). Additional information is used from Bowling *et al.* (1993).

2.2 LAGOON MORPHOMETRY.

Morphometric characteristics of the lagoons were obtained from aerial photographs and 1:25.000 topographical maps using a Tamaya Planix 7 planimeter. Geomorphological analysis of the lagoons was based on aerial photographs, topographical maps, ground photographs and field

investigations.

Maximum depth (Z_{max}) was measured by placing a graduated rope across the lagoon, between identifiable points on the ground and map, and measuring depth with both a plumb line and a hand held depth sounder from a small inflatable raft This procedure was repeated several times, depending on size and shape of the individual lagoon. From this information contoured bathymetric maps were compiled for many of the lagoons investigated.

2.3 PHYSICOCHEMICAL SAMPLES.

Water samples for physicochemical analysis were collected simultaneously with the biological sampling of the respective lagoons. Water samples for laboratory analysis were collected in acid rinsed, opaque polyethylene bottles from 10-20 cm below the surface following rinsing with lagoon water. Samples were stored in the dark and on ice until return to the laboratory and all measurements were made as soon as possible (2-3 days) after sampling.

Water colour (gilvin) was measured at 440 nm (g_{440})(Kirk 1976). Samples were passed through 0.45μm membrane filters and the filtrate obtained was measured with a Cecil CE 292 digital UV/VIS spectrophotometer against a distilled water blank in 4 cm quartz glass cuvettes at 440 nm. The measured absorbance values were converted to a 1 m pathlength and multiplied by 2.303 to give the natural logarithmic absorption coefficients in m^{-1} (g_{440}).

Turbidity (Tn) was measured in a Hach 2100 nephelometric turbidimeter against formazin standards and values expressed in NTU (Nephelometric Turbidity Units) Turbidity values in NTU may be taken to be approximately equal to the scattering coefficient (in units of m^{-1}) of a natural water (Kirk 1986).

Conductivity measured as K_{25} was obtained by laboratory and field electrometric measurements using a WTW LF191 electronic meter and a dip type probe

pH was also obtained by laboratory electrometric and in situ measurements using a Metrohm E558 electronic pH meter (accuracy +/- 0 1 pH unit) and a dip type probe

Water samples were collected for laboratory analysis of DOC, major cations (Na^+, K^+, Ca^{2+}, Mg^{2+}) and major anions (SO_4^{2-}, HCO_3^-, Cl^-). These were stored at 4 ^{0}C until analysis using standard methodology (APHA 1971).

Dissolved oxygen (DO_2) was obtained by field electrometric measurements using a WTW OXI 191 electronic meter and a dip type probe, on two separate occasions for most of the wetlands during the reconnaissance of the North East lagoons in 1991-1992. When equipment permitted, during the intensive study, the North East lagoons were measured on each occasion. Measurements on the shallow NE lagoons were taken at the surface (10 cm depth) and at the sediment and water interface (1.0-1.5 m depth depending on water level) The deeper lagoons of the West Coast were measured at the surface and one metre intervals to determine if they were subject to stratification and also to determine the onset of turnover.

Additional water samples for Chlorophyll a analysis were filtered through Whatman GF/C glass fibre filters and immediately afterwards the filters were extracted in 10 ml of 100% methanol, stored in the dark, at 4 ^{o}C for 24 hours The filtrate was then centrifuged at 3,000 rpm for 15 minutes The supernatant was then withdrawn carefully so as not to disturb any sediment. Without delay and in subdued light the extinction of the solution was measured spectrophotometrically at

E664 and E750 (Where E = absorbance at wavelengths at 664 nm and 750 nm).

Chlorophyll a (C) was calculated by the equation

$$C\ \mu g./l = 13.333(E664 - E750)$$

corrected for volume of water filtered by the equation.

$$\mu g \text{ chlorophyll a } /l = C/V$$

where V = volume of water filtered

Chlorophyll has an absorption maximum at 664 nm. An approximate correction for coloured compounds and for turbidity can be made by subtracting the absorbance at 750 nm where chlorophyll absorbs an insignificant amount of light.

Major nutrients were analysed. Water samples were collected in acid rinsed opaque polyethelyne bottles from the five NE lagoons intensively sampled between November 1993 to October 1994. These were immediately stored in ice and placed in the dark in the field. The samples were analysed for the major nutrients, Total Phosphorus (TP), Nitrate (NO_3) and Nitrite (NO_2) by the Tasmanian Government Analyst using standard methodology (APHA 1971) upon return to Hobart

2.4 BIOLOGICAL SAMPLING.

Zooplankton and phytoplankton samples were collected by single or several oblique tows in deeper lagoons and by hand held 20 μm and 200 μm conical nets in the more shallow pools and lagoons. All collections were preserved in 5-10% formalin, pending taxonomic identification. Nets were washed thoroughly before and after the sampling of each site in an effort to reduce the possibility of contaminants in the samples obtained.

In the intensive study of lagoons on the North East coastal plain (chapter 6), six lagoons were sampled on each occasion with a 20 μm and a 200 μm conical net. The presence/absence of microcrustacea (identified to genera or species where possible) was recorded, with results for the two nets pooled. In addition a known quantity of water was filtered through a 200 μm net to obtain a quantitative microcrustacean sample. The volume of water filtered depended on depth of the lagoon at time of sampling and varied from 20-40 litres of water and numbers for individual species per litre counted. All animals were sorted, identified to species if possible and counted. The sample was not sub-sampled so as to obtain uncommon species. Numbers of individuals were corrected to number/litre.

2.5 TAXONOMY

Taxonomy of the Crustacea·Calanoida:Centropagidae is based on the morphology of the male fifth pair of thoracic legs. The males, distinguished by geniculate antenna, were transferred to a slide and mounted in polyvinyl alcohol, the male limbs were then carefully teased away from the body and identified using Bayly (1961, 1962, 1963, 1964b, 1992) as reference texts. Identification of species is only possible on the mature reproductive adult form.

Reference texts used in the identification of the Crustacea:Cladocera were: Smirnov (1976) for the *Ilyocryptus* sp. (now Ilyocryptidae, Smirnov 1992); Smirnov (1992) for the Macrothricidae.

Several references were used for the Daphniidae: Sergeev and Williams (1983, 1985) and Sergeev (1990) for *Daphniopsis*; Herbert (1977) and Benzie (1988) for *Daphnia*; Flössner (1972) and Greenwood *et al* (1991) for *Ceriodaphnia*; Flössner (1972) and Dumont (in Smirnov & Timms 1983) for *Simocephalus*; and Korinek (in Smirnov & Timms 1983) for *Bosmina*. Several references were used for Chydoridae identification: Smirnov and Timms (1983), Frey (1991a, b); and Shiel 1995.

Methods used in the identification of the cladocera were those of Dodson & Frey (1991) and disarticulation after the methods of Megard (1964). Identification of the cladocera is based on the morphology of the head shield, shell valves, legs, antenules and postabdomen. Therefore, unlike the calanoids, taxonomic identification of this group was involved and time consuming. Many of the individual specimens required clearing of body protoplasm, and organic debris from the body surface and from internal body chambers, to discern taxonomic features and for dissection. Several methods were used with varying success and some individual specimens were subjected to more than one process.

(1) Preserved specimens were heated in 1-2 ml of concentrated KOH in microscope cavity slides over the flame of a spirit lamp for five to ten minutes. This was then inspected under a compound microscope, once the KOH had cooled and fumes subsided, to see if the specimen had been cleared sufficiently to allow identification and/or dissection Often a second or third heating was required.

(2) This procedure was repeated using concentrated HCL for stubborn samples. Care was taken not to boil the KOH or acid to avoid spattering and to prevent premature separation and possible loss of body parts

(3) The specimen was left to stand in cold concentrated HCL or KOH for at least 24 hours prior to heating. Some specimens required being subjected to all three methods to varying degrees before clearing was completed.

Once cleared, the chitinous exoskeletal structures of the specimen, such as the headshield, shell valves, postabdomen, labrum, mandibles and legs are still intact and loosely attached to each other The specimen was then removed from the cavity slide whilst still intact, and mounted in polyvinyl-lactophenol mounting medium on a standard microscope slide. Under a Wild M5 6-50x dissecting microscope and using very fine tungsten dissecting needles, the exoskeletal components were carefully separated, and arranged in the correct orientation within the mounting medium for taxonomic identification A coverslip was then placed over the prepared specimen Identification was completed using a Zeiss RA compound microscope with bright field background.

A major problem encountered with samples from the NE lagoons was in the sorting of individual specimens. These often had to be individually untangled from a mucilage of *Microcystis* and other blue-green filamentous algae before identification was possible.

A problem encountered early in the study of the North East lagoons was in the time it took to sort through a sample, particularly in the quantitative study. Samples were often "dirty" with filamentous algae, organic debris and fine organic particulate matter. Many of the dystrophic lagoons had very high loads of very fine suspended particulate organic matter, so that nets would become clogged in a single tow. Sorting of these samples took from between 1-10 days each.

2.6 ANALYSIS OF DATA.

Univariate analysis is often used to test for the level of significance between variables and categories. The program SAS version 6.06 was used to test the significance between differences in lagoon categories, physicochemical data variables and species richness.

There are many multivariate statistical techniques that can be applied to ecological data Principal components analysis is one of the simplest.

Principal Components Analysis (PCA) is a means of simplifying the data by reducing the number of variables to those that explain the most variation in the data (Manly 1994). The best results are obtained when the original variables are highly correlated, positively or negatively, then the number of original variables can be reduced to two or three principal components (PC1-PC2-PC3.... etc.) that explain the largest amount of variation. PCA may be defined as maximising the variance of sample points along each axis, with variance decreasing from PC1-PC2-PC3 and so on. It is a useful tool for interpolation of data as PC1 explains the n% of total variance in the original sample. The % variance explained by PC3 is small therefore you may dispense with this PC, to give a two dimensional "ordination plane", since PC1 and PC2 account for a high % of total variance. This analysis is a way of accounting for the variation in data as concisely as possible.

Principal components analysis (PCA) is sometimes referred to as a method of ordination. That is to say it is a method for producing a small number of axes against which a set of objects of interest may be plotted. The positions of these objects of interest are plotted in the multivariate space generated by many measurements onto a small number of axes. The relative position of these objects is then displayed in a way that is easily assimilated. The statistical program BIOSTAT II was used to analyse the environmental data for PCA

In this study the environmental data obtained for both of the North East studies and the West Coast was analysed. The data was standardised. Eigenvector values for each of the environmental variables for the first two principal components, PC1 and PC2, were then plotted as X-Y coordinates to give a two-dimensional picture for ease of interpretation. The component scores for each of the respective sites were similarly treated and also plotted to determine the degree of clustering.

The statistical package PRIMER was used to sort the respective sites, based on their community data, into similar classes. PRIMER uses the Bray-Curtis similarity co-efficient to group sites, based on community presence/absence data, into classes so that similar ones are in the same class. This analysis was done to define "true" groups and for data reduction. Conversely if the dendrograms produced, generate unexpected groupings, then this might in itself suggest relationships to be investigated. The interrelationships between sites and sampling date where then mapped in an ordination by non-metric multi-dimensional scaling (MDS) in an attempt to visualize the community patterns.

The PRIMER program SIMPER was used to analyse the pooled temporal community data for identification of key species for each of the lagoon groups. SIMPER calculates the Bray-Curtis dissimilarity between all pairs of inter-group samples (-i.e every species in group one paired with every species in group two). The Bray-Curtis dissimilarity is then averaged over all pairs and then broken down into the separate contribution from each species to the overall dissimilarity between the two groups. Indicator species were identified as those species which contributed the greatest percentage of dissimilarity to separate faunal assemblages of the three different groups of lagoons.

CHAPTER 3.
LIMNOLOGY OF COASTAL LAGOONS IN NE TASMANIA.

3.1 ABSTRACT.

The North East coastal plain of Tasmania contains many dune lakes occurring on siliceous and calcareous dunes. All are polymictic, span a range of nutrient states, are of variable depth and show strong seasonal trends Most have extensive submerged and emergent macrophyte communities. Physicochemically these dune lakes are similar in many ways to those in temperate parts of mainland Australia, Tasmania and the Bass Strait Islands, being of low to moderate salinity, moderate to high dystrophy and having a seawater ionic dominance They differ in that they are more alkaline than the majority of Tasmanian and mainland Australian lagoons, and markedly astatic relative to most Tasmanian lagoons

3.2 INTRODUCTION.

Significant proportions of Tasmania are fringed by sandy coastal lowlands which often contain freshwater dune lakes and wetlands. The North East coastal plain of Tasmania contains many dune lakes occurring on siliceous and calcareous dunes (**Figure** 3.1). The origins of lagoons in the North East Tasmanian coastal lowlands differ depending upon whether they are on the leeward or windward coast with regard to the prevailing westerly winds. Coastal ridges of parabolic and transverse dunes have formed on western facing shores and frontal dunes on shores with an easterly aspect. Interdigitating these ridges are a number of ephemeral, astatic and permanent freshwater dune lakes. The geomorphic origins of Australian freshwater coastal dune lakes have been broadly classified by Timms (1982, 1986a, 1992). Although perched dune lakes (type i) are the most common coastal lagoon in mainland Australia (Bayly 1964a, Timms 1982), in Tasmania lagoon origins are more diverse (Bowling *et al.* 1993). In the NE some are lowland dune lakes (type ii), surface expressions of the ground water table in small depressions located behind frontal dunes (type iii or vi). Others are dune contact lakes (type iv).

Although Tasmania is generally more humid than continental Australia, much of eastern Tasmania is subject to summer drought and severe soil water deficits. In the North East, rainfall is highly seasonal with more than 80% occurring between April and October (**Figure** 3.2). The seasonality of rainfall has a significant influence on the limnology and ecology of the lagoons

3.3 AIMS.

The aims of this part of the study were twofold:

a) To investigate the physical and chemical aquatic environment of permanent, markedly astatic and ephemeral coastal lagoon ecosystems, and

b) To compare the degree of change in physical and chemical parameters in seasonally ephemeral and permanent lagoons respectively.

Particular attention was focused on the role of the hydrological regime of markedly astatic and seasonally ephemeral lagoons.

3.4 STUDY SITES.

The lagoons studied lie on the relatively extensive, sandy coastal plain on the North East of Tasmania (**Figure** 3.1). Longitudinal dunes of Pleistocene siliceous sands cover approximately 350 km^2 in North East Tasmania. They are a result of changes in the climatic regime within the Pleistocene when Bass Strait was an exposed sandy plain of low relief. Holocene parabolic dunes of

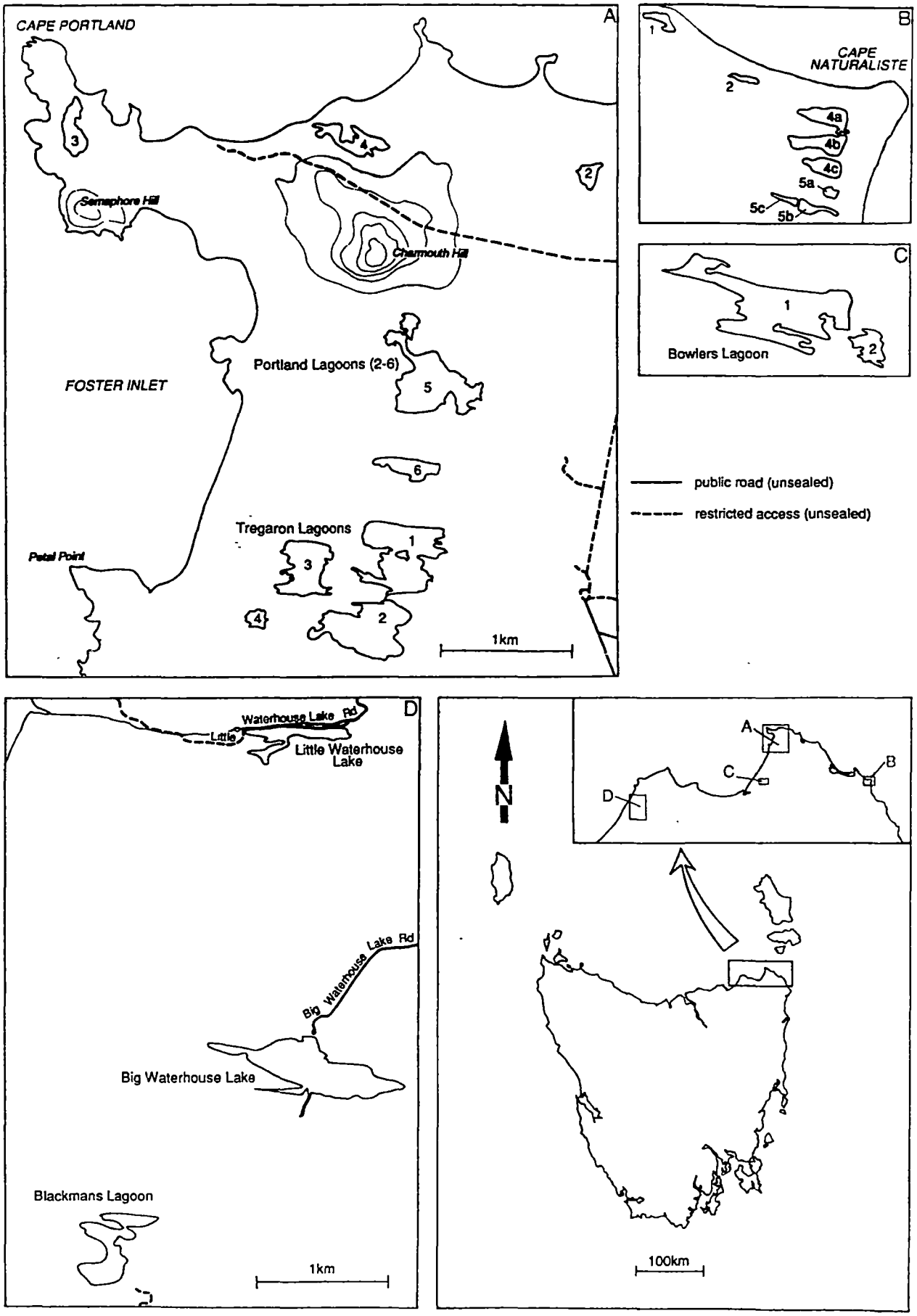


Figure 3.1 Maps of North East Tasmania showing the locations of lagoons on the North East Coastal Plain.

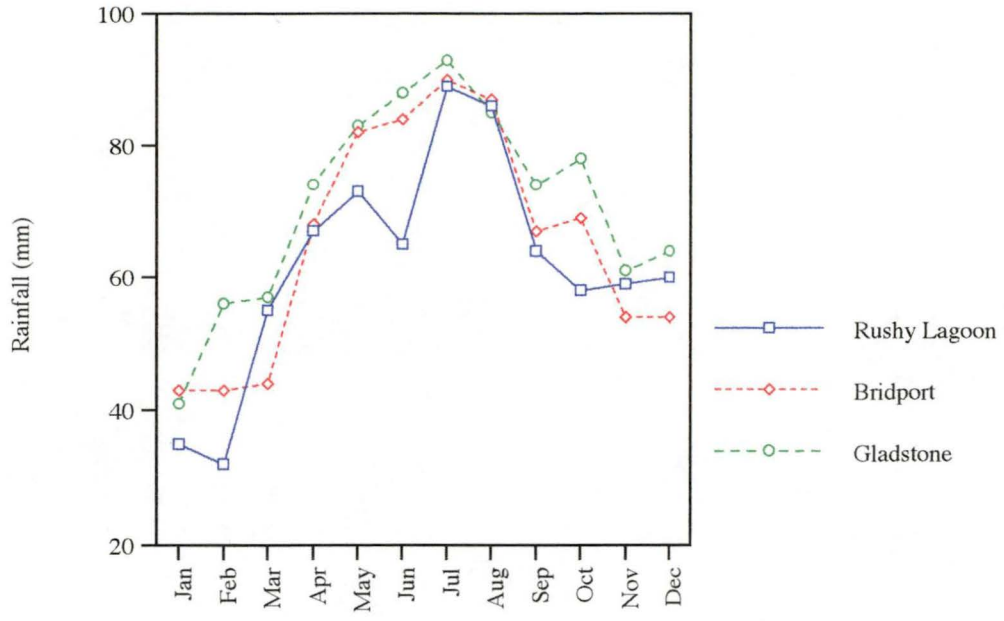


Figure 3.2 (A) Mean monthly rainfall for the period 1908-1991 using all available data (Bureau of Meteorology).

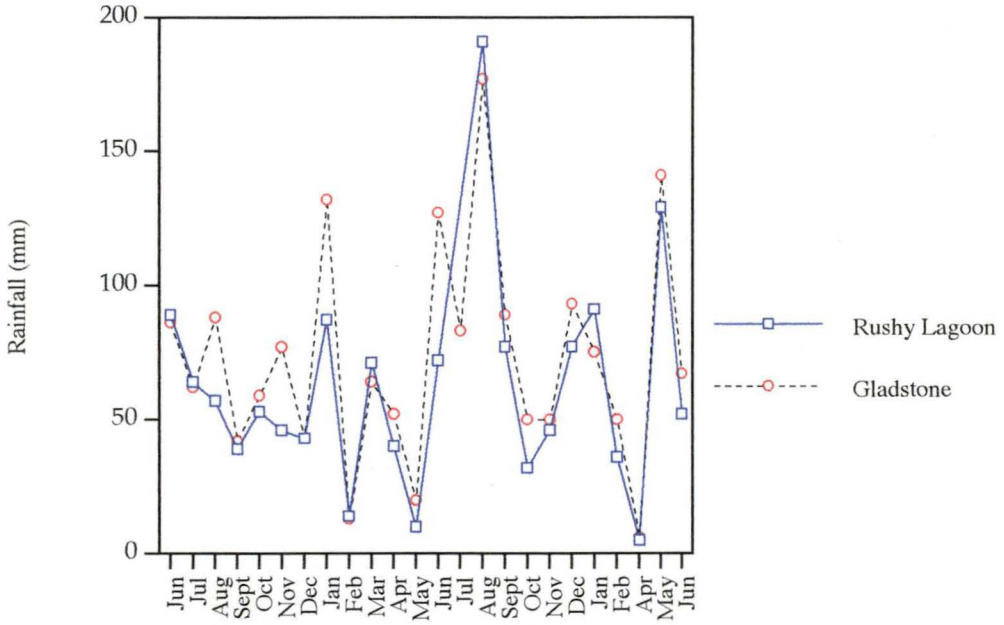


Figure 3.2 (B) Monthly Total Rainfall for the period June 1990-May 1992. Bureau of Meteorology.

calcareous sands up to 2 km in length, that occur in close association with the Pleistocene dunes have formed under wind influence since the marine transgression of Bass Strait (Bowden 1978), that separated Tasmania from the Australian mainland. The sandy plain and the dune systems (**Plate** 1) form an unconfined aquifer draining the North East coastal plain (Bowden 1978).

Cape Portland (**Figure** 3.1a). Lagoons No. 1, No 2 and No. 4 are "type iv dune contact lakes" (Timms 1982, 1986a), lying between the dolerite outcrop of Charmouth Hill (53 m asl) and a 3.5 km long narrow foredune between 50-300 m wide and up 22 m high. A sandy soil mantle overlies the dolerite bedrock except for exposed, weathered dolerite boulders. Lagoon No 3 occupies a shallow deflation basin in sandy soil overlying dolerite bedrock, it lies less than 50 m from the sea and is extremely exposed to the prevailing winds To the east the lagoon is separated from the sea by a 2 m high shingle bar between two small, low-lying dolerite hills. Seawater may overtop the shingle bar during storms. Lagoon No. 5 (**Plate** 2) is possibly a dune contact lake, sandwiched between active longitudinal dunes to the south and Charmouth Hill to the north. Cape Portland Lagoon No. 6 is a "type ii lowland dune lake" located between the trailing arms of an active parabolic dune (**Plate** 3).

Tregaron Lagoons (**Figure** 3 1a). Bowling *et al.* (1993) suggests that these are perched lagoons (Timms 1982, "type i"), lying between a series of old vegetated longitudinal dunes barred by mobile transverse dunes. The lagoons are only several metres above sea level They may be better considered as "type ii" lowland lakes, i.e. surface expressions of the groundwater table, draining the low-lying hills 3.5 km to the east and Ringarooma Tier 1 km to the south (**Plate** 4 & 5).

Cape Naturaliste (**Figure** 3.1b). The siliceous sands of Cape Naturaliste form a narrow coastal plain 2-3 km wide and 14 km long between Mt. William (**Plate** 1) to the west and the sea to the east. These sands form a mantle overlying impermeable granite and they form an unconsolidated aquifer with drainage from inland hills. This narrow plain contains many shallow, ephemeral swamps and lagoons, and is largely devoid of natural surface drainage. The Cape Naturaliste lagoons are close to one another and 100-300 m from the sea behind a single foredune. The predominant vegetation is of low coastal heath. The lagoons are only 2 m above sea level and fit the description of Timms' (1982) "type ii lowland lakes" (**Plates** 6-9).

Bowlers Lagoon (**Figure** 3.1c). This lies on the old flood plain of the Ringarooma River, between the base of Ringarooma Tier (120 m high) and the calcareous sands of Boobyalla Beach 1 km to the west. Ringarooma Tier is a 10 km escarpment, with waters draining this escarpment forming an extensive region of intermittent swamps between the foredunes of Boobyalla Beach and base of the escarpment. The lagoon lies between the arms of an active parabolic dune (**Plate** 10). It is a remnant of a much larger waterbody and is in the process of being obliterated as the dunes advance.

The Waterhouse Lagoons (**Figure** 3.1d). Big Waterhouse Lake is located between two stable Pleistocene longitudinal dunes that support a eucalypt woodland with a low dense understorey The lagoon is fed by Sheepwash Creek draining the low-lying sandy coastal plain to the south east The lagoon has had an outflow to the sea, but this was dammed by an active transverse dune approximately twenty years ago, raising the level of the lagoon by approximately 1 m, and inundating large fringing marsh areas to the east and west of the lagoon (**Plate** 11).

Little Waterhouse Lake (**Figure** 3.1d) is a dune contact lake The lagoon is long and narrow, lying between a longitudinal dune to the west, and abuts a small dolerite hill to the East The water

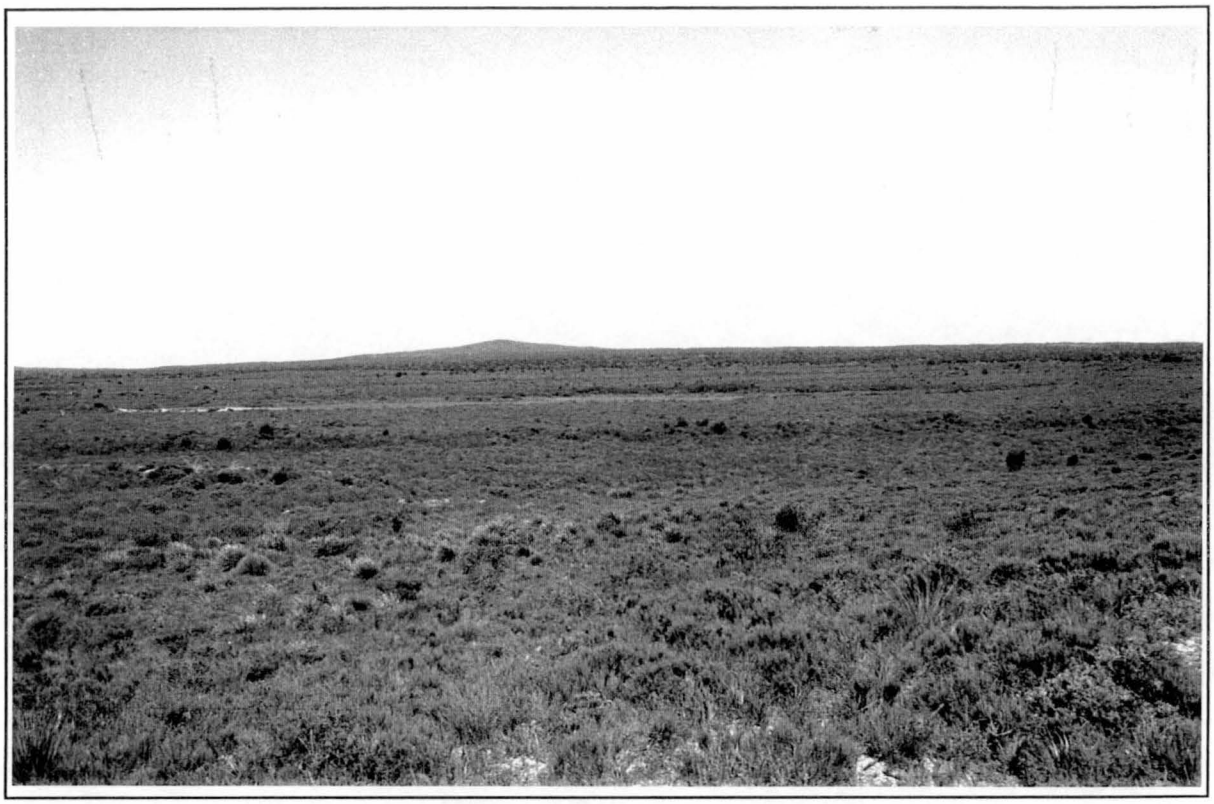


Plate 1. The North East Coastal Plain with Mt. William in the background.

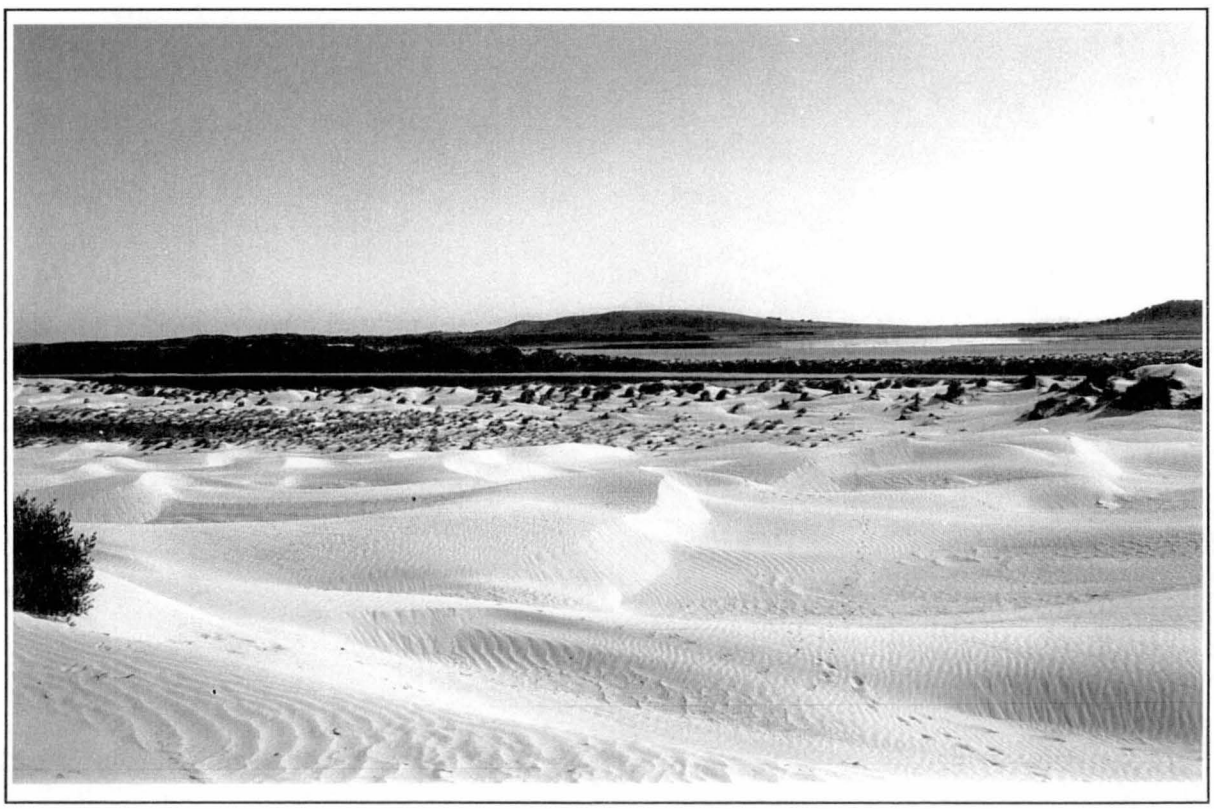


Plate 2. Cape Portland Lagoon No. 5. Charmouth Hill is visible in the background (centre).

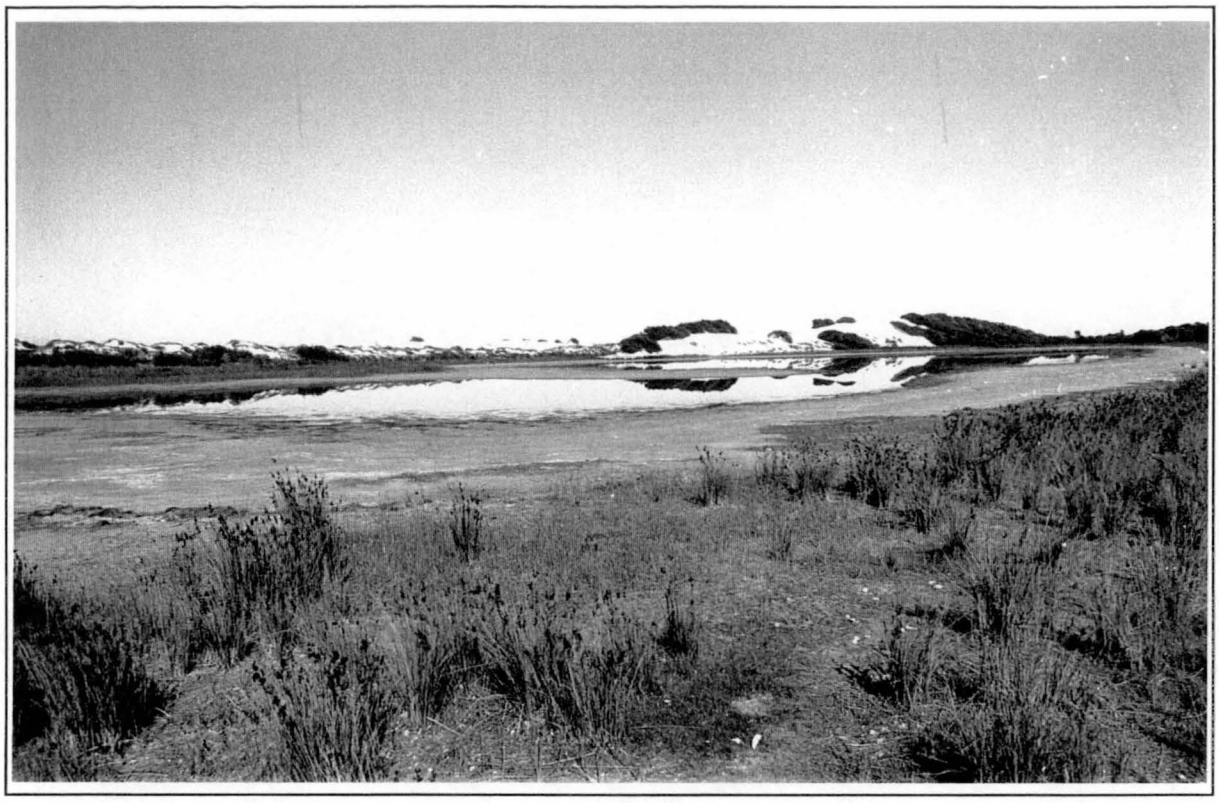


Plate 3. Cape Portland Lagoon No. 6 showing the active parabolic dune in the background.

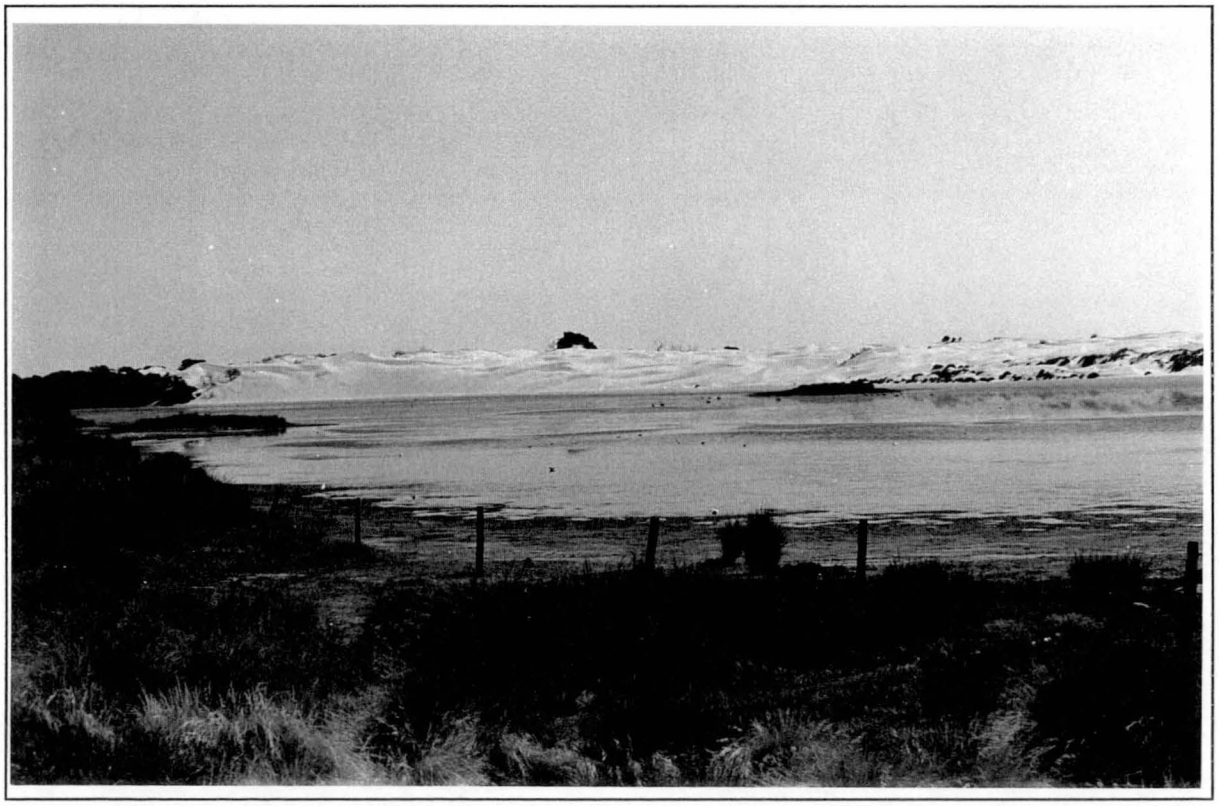


Plate 4. Tregaron Lagoon No. 1 with a mobile transverse dune in the background.

Plate 5. Tregaron Lagoon No. 5. Inundation of the Tregaron Lagoon by a mobile transverse dune is shown.

Plate 6. Cape Naturaliste Lagoon No. 1. A Type II lowland lake. The foredune is shown to the left of the plate.

Plate 7. Cape Naturaliste Lagoon No. 2. A Type II lowland dune lake. The foredune is to the right of the plate.

Plate 8. Cape Naturaliste Lagoon No. 4a (foreground - left) & Lagoon No. 4b (background - right).

Plate 9. Cape Naturaliste Lagoon No. 5a. A Type II lowland dune lake. The foredune vegetated with low coastal scrub is visible in the backgound.

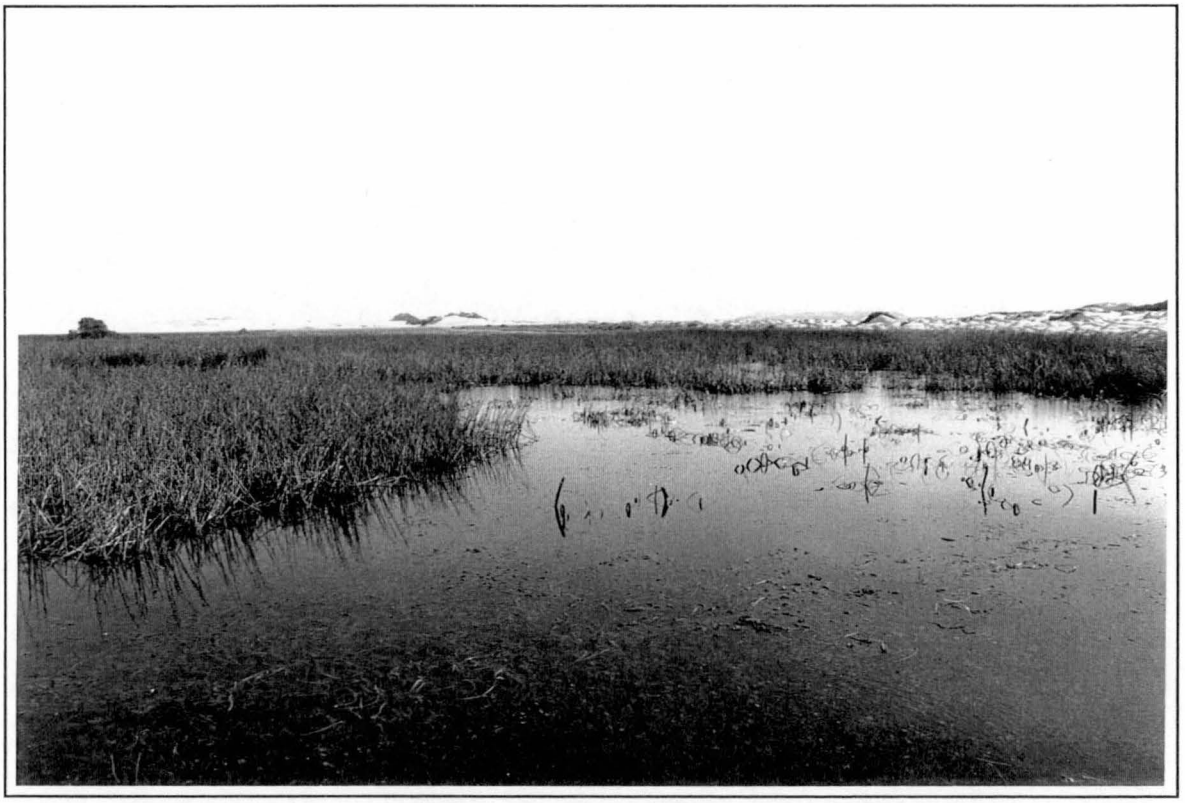


Plate 10. Bowlers Lagoon No. 1. Active parabolic dune is visible in the distant background.

Plate 11. Big Waterhouse Lake.

level of this lagoon has been raised by the construction of an earthen dam across the original outflow to the sea, with the impounded water backing up between the dune and hill.

Blackmans Lagoon (**Figure** 3.1d) is similar to Big Waterhouse Lake, lying between two old longitudinal dunes. Dune barring by active dunes has provided a barrage, behind which the lagoon has formed. A number of agricultural drains, dissecting the flat low lying land to the south of the lagoon, lead into it augmenting the natural inflow.

3.5 METHODS

Water samples for physicochemical analysis were collected approximately at three to four month intervals between August 1991 and September 1992 from twenty lagoons between Cape Naturaliste and the township of Bridport. This broad scale approach was mainly to provide an indication of the variation among the lagoons, covering a range of lagoon types over the study area, i.e. a reconnaissance. A detailed description of methods used is given in Chapter 2.

3.6 RESULTS.

3.6.1 Morphometry.

Morphometrical data is presented in **Table** 3.1. Surface areas of the water bodies varied from <1 ha to >1 km^2. Big Waterhouse Lake is the largest of the lagoons with a surface area 1.26 km^2, followed by Cape Portland No. 5 and Tregaron No. 1 both 23 ha in size. The remaining lagoons were small with a surface area, when full, of between 1-6 ha The surface water area of the ephemeral Cape Portland and Cape Naturaliste lagoons was dependent upon season and rainfall

Maximum depths did not exceed 2.5 m, and most of the lagoons were 1 m or less in depth (**Figures** 3.3-3.5). The shallowness is reflected in the relative depths (Z_r) of the lagoons. Z_r is the relationship of Z_{max} to the mean diameter of the lake. The majority of the lagoons have values between 0.18%-0.44%.

The lagoons varied in shape from nearly circular to very elongated. Shoreline development (D_S) ranged from 1.04 (D_S) in Cape Naturaliste No. 5a to values of 1.98 (D_S) and 2 1 (D_S) for Cape Portland No. 4 and No. 5. The Cape Naturaliste lagoons are simple in shape. They are unbranched, circular to pennate, or triangular. This reflects their orientation to the prevailing winds. In contrast, the Cape Portland lagoons and the Waterhouse series are branched lagoons with D_S values between 1.5 and 2.41.

3.6.2 Physico-chemical Parameters.

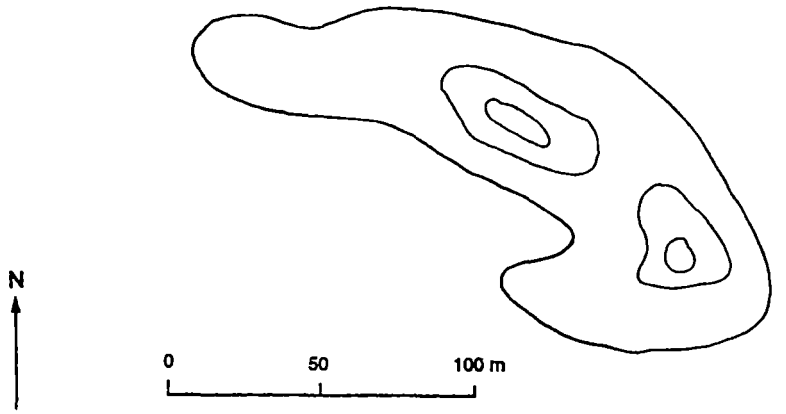
Limnological conditions are summarised in **Appendix** 1. The shallowness of the lagoons, the large surface area relative to depth, and exposure to frequent strong winds ensures thermal stratification is unlikely.

The conductivities and salinities (**Appendix** 1) of most lagoons were moderate to hyposaline (K_{25} = 500-1500 μS cm^{-1}), apart from the saline lagoons of Tregaron No. 1 and Cape Portland lagoons. As expected from the ephemeral nature of individual lagoons, K_{25} of the surface waters varied considerably between sampling, due to strongly seasonal rainfall and evaporative concentration of salts.

The g_{440} values of most of the lakes sampled indicates moderate (g_{440} 1< 5.0 m^{-1}) to very high dystrophy (g_{440} 10<25.0 m^{-1}), and one, Cape Naturaliste No. 2, is extremely dystrophic or

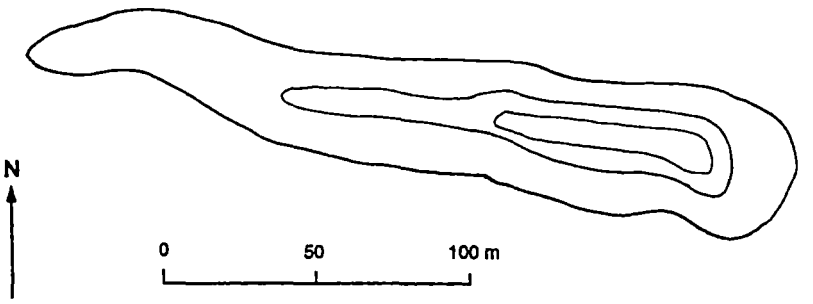
Site	Zmax(m)	Zeu(m)	Relative depth	Surface	Length of	Ds	Description	Lake Type
			Zr (%)	area (ha)	shoreline (m)			
Cape Naturaliste No1	1.50	0.25	0.94	002.00	650	1.29	Holocene Frontal dune on siliceous sands	Lowland dune (type ii)
Cape Naturaliste No2	1 00	0.10	0.79	001.25	525	1 32	Holocene Frontal dune on siliceous sands	Lowland dune (type ii)
Cape Naturaliste No4a	1.00	0.25	0.44	004.06	1100	1.54	Holocene Frontal dune on siliceous sands	Lowland dune (type ii)
Cape Naturaliste No4b	0 50	0 25	0.25	003.20	1075	1.69	Holocene Frontal dune on siliceous sands	Lowland dune (type ii)
Cape Naturaliste No4c	0.50	*	0.28	002.50	725	1.29	Holocene Frontal dune on siliceous sands	Lowland dune (type ii)
Cape Naturaliste No5a	<0.5	*	0.41	001.17	400	1.04	Holocene Frontal dune on siliceous sands	Lowland dune (type ii)
Cape Naturaliste No5b	<0.5	*	0.31	002.00	725	1.45	Holocene Frontal dune on siliceous sands	Lowland dune (type ii)
Cape Naturaliste No5c	<0 5	*	0.44	001.00	*	*	Holocene Frontal dune on siliceous sands	Lowland dune (type ii)
Cape Portland No1	<0.5	*	*	000.50	*	*	Holocene Frontal dune	(type iv)
Cape Portland No2	0 50	*	0.44	001 00	550	1.55	Holocene Frontal dune + Dune contact	(type iv &vi)
Cape Portland No3	1.00	*	0.38	005.30	1350	1.65	Dune contact lagoon with dolerite ?	Dune contact (type vi)
Cape Portland No4	0.50	0.92	0.18	006.25	1750	1.98	Dune contact lagoon with dolerite	(type vi)
Cape Portland No5	1.00	0.63	0.18	023.10	3580	2.10	Parabolic & dolerite Dune contact	(type iv &vi)
Cape Portland No6	1.00	0.71	0.40	005.00	1175	1.48	Parabolic dune	Lowland dune (type ii)
Bowlers Lagoon No1	5.00	1.90	0 71	039.10	5350	2.41	Transverse calcareous dune	Lowland dune (type ii)
Bowlers lagoon No2	2 50	2.22	1.01	004 79	1125	1.57	Transverse calcareous dune	Lowland dune (type ii)
Tregaron Lagoon No1	2.00	1.14	0.37	023.00	3200	1.88	Transverse calcareous + Longitudinal dune	Lowland dune (type ii & iii)
Tregaron Lagoon No2	2.00	*	0.41	019 00	3250	2.10	Transverse calcareous + Longitudinal dune	Lowland dune (type ii & iii)
Blackmans lagoon	4.00	*	0.95	014.00	2825	2.13	Parabolic siliceous dunes	Lowland dune (type ii)
Little Lake Waterhouse	4 00	*	1.25	008.10	2050	2.03	Dune contact lagoon with dolerite	(type vi)
Big Lake Waterhouse	4.50	*	0.36	126 00	5300	1.32	Transverse calcareous + Longitudinal dune	Lowland dune (type ii)

Table 3.1 NE Tasmanian site morphometry and site description



Cape Naturaliste Lagoon No 1
(contour interval 0.5m)

Figure 3.3 Bathymetry of Cape Naturaliste Lagoon No 1. NE Tasmania



Cape Naturaliste Lagoon No 2
(contour interval 0.5m)

Figure 3.4 Bathymetry of Cape Naturaliste Lagoon No 2. NE Tasmania

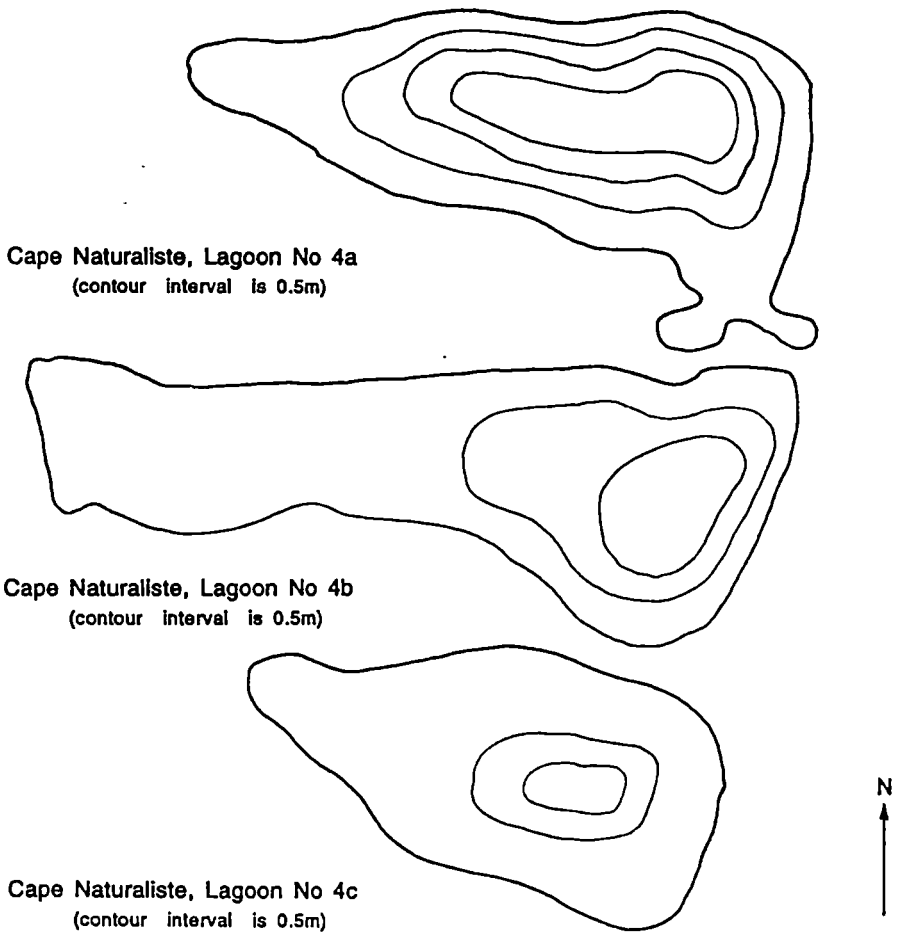


Figure 3.5 Bathymetry of Cape Naturaliste Lagoon No 4 (A-B-C). NE Tasmania.

"blackwater" Seasonal variation in colour is apparent in all lagoons, particularly for Cape Naturaliste No. 2 and Cape Portland No 5 and No. 6.

pH values are circum-neutral to slightly alkaline, predominantly between 6.5-8.0 reflecting the brackish and calcareous nature of the lagoons. The exceptions are the more dystrophic Cape Naturaliste lagoons and the alkaline Cape Portland lagoons which had lower and higher pH values respectively. All lagoons showed various degrees of temporal variation in pH.

Na and Cl are the major ions in all the lagoons. Most of the Cape Naturaliste and Portland lagoons had a seawater ionic dominance of Na>Mg>Ca>K:Cl>SO_4>HCO_3 (**Figure** 3 6). The exceptions are Cape Portland No. 6 with higher concentrations of K (Na>Mg>K>Ca) and Cl>HCO_3>SO_4. Blackmans Lagoon and the Tregaron lagoons had a seawater cation order and an anionic order with Cl>HCO_3>SO_4 Both Bowlers lagoons and the two Waterhouse lakes had an ionic order of Na>Ca>Mg>K: Cl>HCO_3>SO_4. The bicarbonate enrichment of these lagoons is shown by pH values >7.5. Seasonal variation in the HCO3 and SO4 order of dominance was particularly evident in the Cape Portland and Cape Naturaliste lagoons. This is attributed to rise and fall in seasonal water levels and change in ionic stoichiometry as waters become increasingly concentrated (Buckney & Tyler 1973a)

Chlorophyll values show that the lagoons spanned a wide range of trophic status, with some being oligotrophic e.g. the Cape Naturaliste lagoons, while others mesotrophic. Cape Portland No. 5, on one occassion would be regarded as eutrophic. Visual observation of the lagoon noted water colour was that of a green apple.

Dissolved oxygen was measured on at least two separate occasions for most of the lagoons. None of the lagoons sampled showed oxygen depletion of the sediment water interface. This is attributed to sufficient wind mixing of the shallow wetlands.

PCA of the environmental variables (**Figure** 3.7) indicates the strong positive association with PC1 (axis 1) for the ions Na, Cl, K, and Mg. g_{440} and DOC are positively associated and pH negatively associated with PC2 (axis 2) For the NE lagoons the first principal component (PC1) accounted for 80-95% of total variance for Na, Cl, K, and Mg PC2 accounted for 60%, 65% and 85% of total variance for pH, DOC and g_{440} respectively. When the PC1 and PC2 account for such a high % of in the data, a plot of the individuals (i e. the lagoons) against these two components is useful for looking for clusters PC1 and PC2 component scores plotted as X-Y coordinates revealed 3 groupings that were for ease of interpolation drawn on separate plots but using the same axis (**Figure** 3.8-3.10). These were the Cape Naturaliste lagoons, the Tregaron and Cape Portland lagoons, and the "Waterhouse" series of lagoons (incl. Bowlers Lagoon No. 1 and No. 2).

Due to the number of overprints amongst the "Waterhouse" series of lagoons, a PCA was performed on these lagoons alone (**Figure** 3.11). Each lagoon of this series separated out (**Figure** 3 12). The ions Na, Cl and Mg had in PC1 93% of variance accounted for, and by PC2 between 82-97% of total variance explained for the remaining variables with the exception of K25 and SO4.

3.7 DISCUSSION.

The chemistry of dune ground water is determined by the balance between humus input, which tends to make it more acid, and the calcium carbonate content of the sand, which makes it more alkaline. Groundwater may be high in nutrients from a variety of sources and winds may provide nutrients in the form of salt spray. Nutrient levels in dune groundwater are determined by a balance

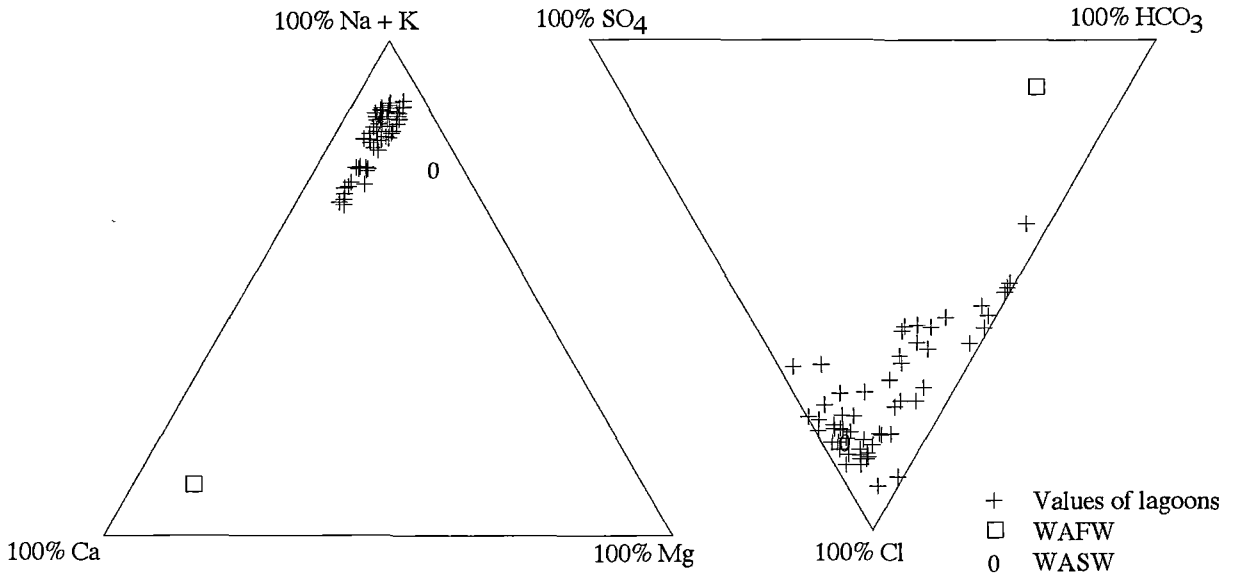


Figure 3.6 Ternary Diagram of Major Ions for NE Tasmanian Dune Lakes 1991-92

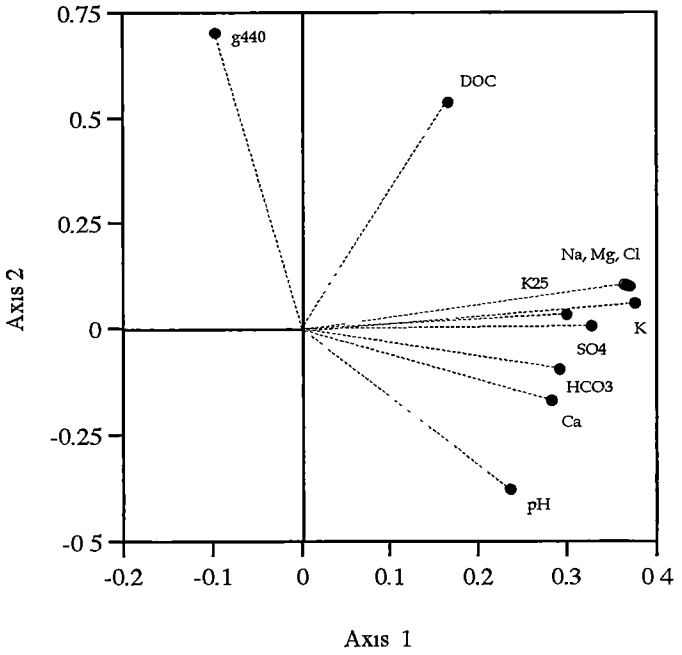


Figure 3.7 PCA plot of eigenvector values for environmental parameters, NE dune lakes Nov.1991-Oct.1992

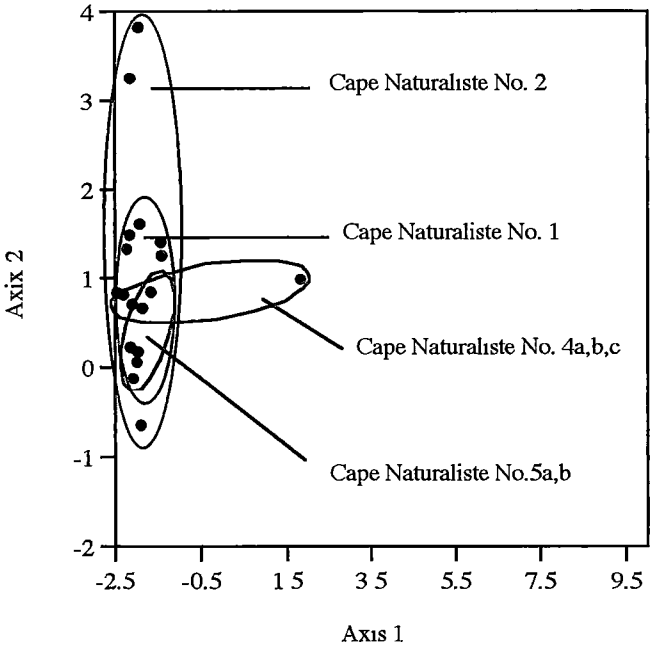


Figure 3.8 PCA plot of component values for Cape Naturaliste dune lakes. Nov.1991-Oct.1992

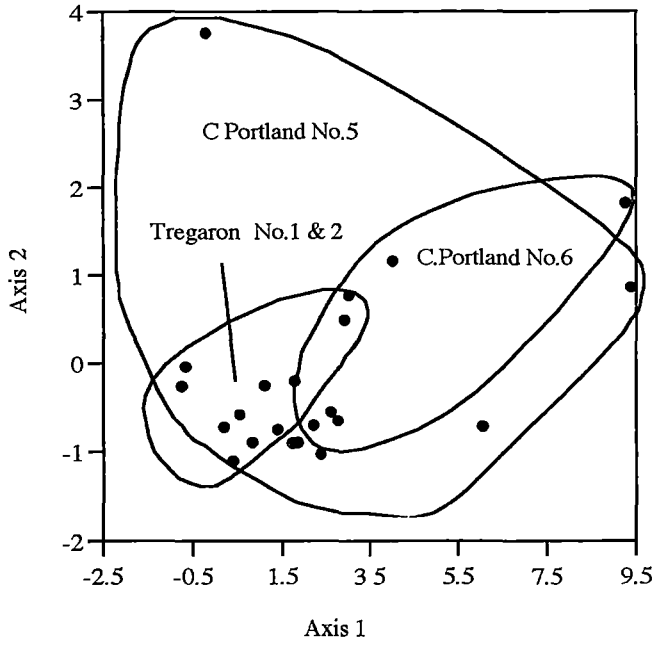


Figure 3.9 PCA plot of component values for Tregaron & C. Portland dune lakes Nov.1991- Oct.1992.

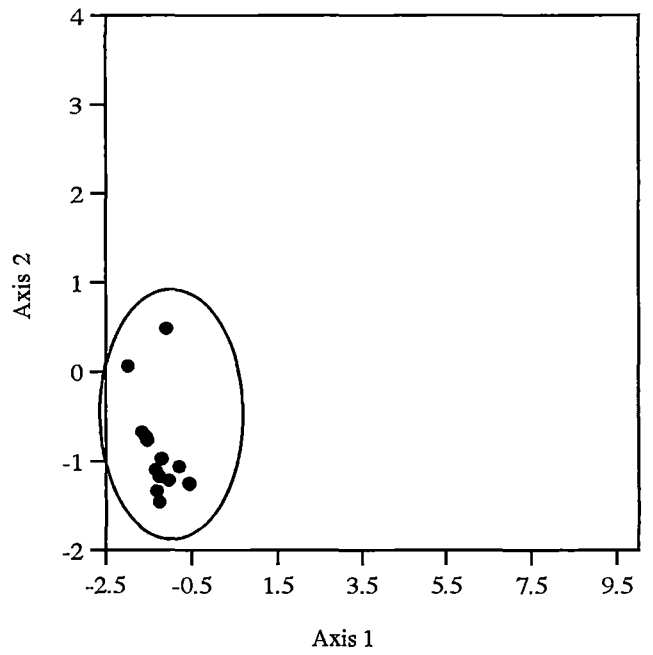


Figure 3.10 PCA plot of component values for Blackmans, Bowlers No.1 & No.2, Big Waterhouse & Little Waterhouse. Nov.1991-Oct.1992

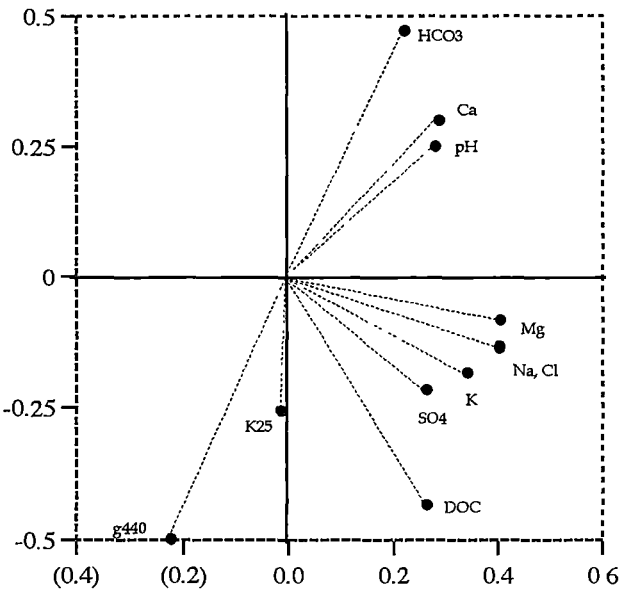


Figure 3.11 PCA plot of eigenvector values NE dune lakes (Blackmans, Bowlers No1 & No2, Little & Big Waterhouse)

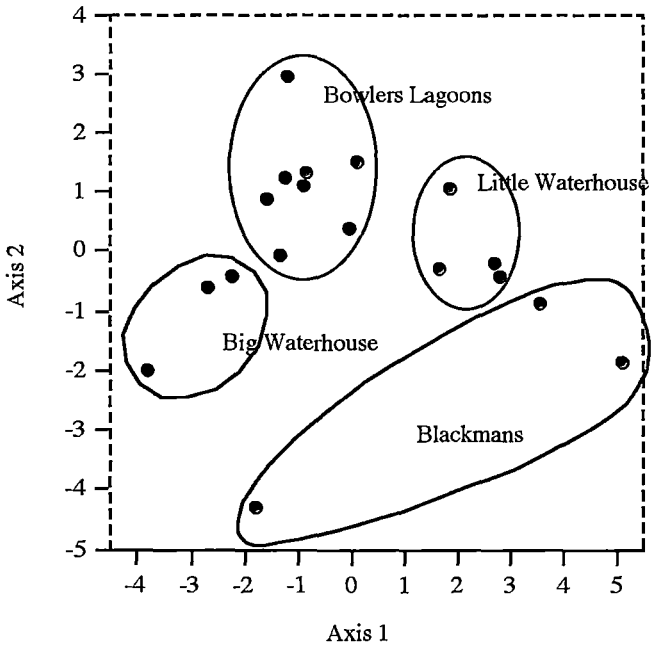


Figure 3.12 Plot of componenet values for Blackmans, Big Waterhouse, Little Waterhouse and Bowlers Lagoon No1 & No 2

of five factors: (1) inputs from weathering of minerals, (2) inputs from the atmosphere, (3) losses by leaching, (4) cycling by the fauna and flora, and (5) storage in the sediments.

3.7.1 Morphometry.

The dune lakes on the North East coastal plain differ from those on the West Coast of Tasmania in their relative depth (Z_r) and maximum depth (Z_{max}), and also in shoreline development (Chapter 7). These morphometric characteristics of the North East lagoons have important implications for their respective hydrological regimes.

Water level fluctuations in the North East lagoons are considerable, and are attributed to the strongly seasonal climate. There is a distinct summer "Dry" and a winter "Wet". Close to 80% of yearly rainfall occurs in the winter months May to September (**Figure** 3 2). Many of the shallow wetlands, i.e. those of Cape Naturaliste and Cape Portland, dry out each summer Deeper and larger dune lakes, such as the Waterhouse lakes, Bowlers Lagoon No. 1 and Blackmans Lagoon, may persist for decades However even these lagoons display some change in surface area and volume. Therefore the lagoons on the NE coastal plain may be placed into three categories: ephemeral, markedly astatic (lagoons that display large variation in depth and surface area) and permanent (**Table** 3.2).

Table 3.2 Permanent and seasonal wetlands of North East Tasmania.

Permanent	Astatic	Ephemeral
Bowlers Lagoon No. 1	Cape Naturaliste No. 4a	Cape Naturaliste No. 1
Bowlers Lagoon No. 2	Cape Portland No. 3	Cape Naturaliste No. 2
Tregaron Lagoon No. 1	Cape Portland No. 5	Cape Naturaliste No 4b
Tregaron Lagoon No. 2	Cape Portland No. 6	Cape Naturaliste No. 4c
Big Waterhouse Lake		Cape Naturaliste No 5a
Little Waterhouse Lake		Cape Naturaliste No. 5b
Blackmans Lagoon		Cape Naturaliste No. 5c
		Cape Portland No. 2
		Cape Portland No. 4

Water levels usually reach a peak by spring and then progressively decrease until winter when substantial rains commence. The large seasonal inflows during winter results in large changes in solute concentrations and conductivity. The degree of change in any particular lagoon will depend upon its depth, its depth relative to surface area, exposure to wind and sun, and height of the groundwater table.

The water table in this region rarely exceeds a depth of 2 m and may rise to the surface after continuous heavy rain during winter months (Bowden 1978). Response to most showers of rain is rapid and usually occurs in a matter of hours.

During summer and until late autumn, the coastal plain may lose up to two thirds of its lagoons/wetlands as a result of evaporation (Steane 1992) The timing of refill of seasonal lagoons appears to be directly in response to rainfall, and is affected by the previous year's rainfall and the

previous year's maximum and minimum water levels. In years of below-average rainfall the groundwater tables are lower, and therefore drying of seasonal lagoons occurs earlier. The timing of drying is primarily a response to the volume of rainfall, while the timing of refill is in response to timing of rainfall. The great variation in seasonal fluctuations in water level with concomitant changes in solute concentrations have important ecological implications, especially at the extremes of concentrations.

In contrast the West Coast lagoons are mainly perched dune lakes, are much deeper and lack a well developed littoral zone. The West Coast lagoons also show, relative to the North East lagoons, little seasonal amplitude in water level fluctuations, and as a consequence are relatively stable in physico-chemical characteristics. The North East lagoons display closer limnological and morphological similarity to the lagoons of Bruny Is (Chapter 8).

3.7.2 Colour (g_{440})

Bowling *et al.* (1986) classified Tasmanian lakes into a number of classes based on g_{440} On this criterion all of the NE lagoons would be regarded as moderate to highly dystrophic. Levels of both g_{440} (colour) and turbidity varied between the lagoons. Coloured compounds mostly consist of the breakdown products from plant material and phytoplankton, largely humic and fulvic acids. These can be formed within the lagoons or transported via surface or groundwater, with concentrations affected by local vegetation types, soil mineralogy and agricultural practices Coloured substances are generally in low concentrations in water draining limestone-rich catchments (Kirk 1983).

The very highly-coloured lagoons occurred in the silicious marine-sand landforms and most of the low-colour dune lakes are in the calcareous sands. Most of the highly-coloured lagoons, those with maximum g_{440} values greater than 15.0 m^{-1}, are also relatively small (<10 ha). The seasonal changes in colour in the wetlands are shown in **Appendix** 1. g_{440} tended to be highest in spring and summer and lowest in winter, probably due largely to the effects of evapo-concentration and dilution, as well as the increased production and release of coloured compounds during the periods of maximum aquatic plant growth. External inputs of colour would also peak in late winter and spring as groundwater and surface water inflows peak.

Dissolved humic substances constitute the most important component influencing the underwater light climates of the lagoons. Although the lagoons are slightly to moderately coloured compared with similar lakes on the Bass Strait Islands (Bowling & Tyler 1984), and for mainland Tasmania (Bowling *et al.* 1993) gilvin concentrations are sufficient to attenuate much of the PAR in the majority of the lagoons In this, the North East lagoons are similar to the freshwater coastal lakes of south east Queensland (Bowling 1988).

3.7.3 Underwater Light Climate

Although the underwater light climate of the coastal lagoons was not measured, for non-turbid waters euphotic depth (Z_{eu}) can be inferred from the g_{440} values (Tyler 1992). If the assumption is made that the empirical relationship between Z_{eu} and g_{440} described by Bowling *et al.* (1986) applies to this system, then the following Z_{eu} values may be estimated (**Table** 3.3). In general, the lagoons would have a predominantly red underwater light climate, with spectral distributions similar to many dystrophic lakes in western Tasmania (Bowling *et al.* 1986).

Light limitation of algal photosynthesis will only occur if the total depth of the water column exceeds the depth of the euphotic zone (Z_{eu}). If the ratio of total depth (Z_{max}) to that of the Z_{eu} exceeds 1 then the wetland is said to be light-limited. The values for this relationship are shown in **Table** 3.3. In general those wetlands with a ratio greater than 1 will lack submerged macrophyte communities except in the shallow littoral fringe where light is able to penetrate to sufficient depth to allow photosynthesis by these plants The majority of the lagoons and associated wetlands in this study have extensive stands of emergent macrophytes with photosynthetic stems above or floating on the surface.

Table 3.3 Mean ratio of Z_{max}: Z_{eu} for selected wetlands.

Wetland	Zeu (m)	Ratio
Cape Naturaliste No. 4a	0.25	4.9
Cape Naturaliste No 4c	0.20	2.5
Cape Naturaliste No 5a	0.12	4.2
Bowlers Lagoon No. 1	1.90	1.2
Bowlers Lagoon No. 2	2.22	1.0
Cape Portland No. 4	0.92	0.4
Cape Portland No. 5	0.63	1.2
Cape Portland No 6	0.71	1 1
Tregaron Lagoon No. 1	1.14	1.2

3 7.4 Turbidity.

The majority of lagoons have relatively low turbidities during periods of low wind, and usually there is little inflow of surface water to bring in allochthonous suspended material. There is no indication of external inputs of inorganic turbidity to the lakes, though a small fraction of the turbidity may be due to loads of sediment carried into the waterbodies during the winter inflows Large external sediment loads would not be expected for most of the lagoons, because they are found mostly in non-eroding landscapes

The shallower lagoons tend to be more turbid because wind-mixing disturbs the bottom sediments. The two extremely high turbidities recorded were in Cape Portland lagoons No 5 and No. 6. Both are very shallow and with large exposed surface areas. Both lagoons are located in an activedune system and possess a sandy substrate The shallowness of the lagoons and their fetch would ensure that even at low wind strength, resuspension of coarse sands would occur.

More moderate turbidities were obtained from the Cape Naturaliste wetlands. These are shallow and have very peaty sediments, so that fine organic particles are continuously resuspended by wind-induced mixing of the water column. Temporal variation in turbidity may be attributed to strongly seasonal winds and chance. Sand and organic particles would rapidly settle in the shallow lagoons on a calm windless day. If the lagoons were sampled before the morning or evening sea breeze, or on a calm day, turbidity would be correspondingly low.

3.7.5 Stratification.

The North East Tasmanian lagoons are too shallow and exposed to strong onshore winds to

allow thermal stratification to develop. The majority of the North East lagoons are less than 2 m in depth and have a large surface area relative to depth, similar to lagoons of Cape York Peninsula (Timms 1986b), North Queensland (Hawkins *et al.* 1988) and north eastern New South Wales (Timms 1982). This is in contrast to the small but deep lagoons of western Tasmania (Chapter 7) and the Jervis Bay region (Norris *et al.* 1993). Z_r values (**Table** 3 1) for the lagoons were low. The behaviour of wetlands of the Swan Coastal Plain, Western Australia (Davis *et al* 1993), suggested that most of the North East Tasmanian lagoons would be completely mixed by winds between 15-20 km h^{-1}. Average wind speed for this region is 25-30 km h^{-1} (Bureau of Meteorology; Bowden 1978). Wind mixing processes would therefore dominate the physical structure of these wetlands, preventing temperature stratification In small dystrophic water bodies under relatively calm sunny conditions, daily cycles of thermal stratification may occur (Jones & Arvola 1984; Bowling & Salonen 1990) Polymixis is a common phenomenon in coastal lagoons (Timms 1969; Bayly *et al.* 1975; Arthington *et al.* 1986, Bowling *et al* 1993).

3.7 6 Chemical Limnology.

The lagoons had Na and Cl as the major ions and most had a seawater order of ionic dominance (Na>Mg>Ca>K: Cl>SO4>HCO3) and seawater ionic proportions (**Figure** 3.6). This ionic order is found in the majority of coastal Australian lakes (Bayly 1964a, Buckney & Tyler 1973a; Timms 1969, 1973, 1977, 1982, 1986a, 1986b; Bensink & Burton 1975; Outridge *et al.* 1989, Norris *et al.* 1993) and is characteristic of freshwater coastal dune lakes in Tasmania (Bowling & Tyler 1984; Walsh 1991; Bowling *et al.* 1993). The exceptions were Big Waterhouse Lake and Little Waterhouse Lake, and Bowlers Lagoon No 1 and No 2 with an ionic order of Na>Ca>Mg>K. $Cl>HCO_3>SO_4$ as these lagoons were located on calcareous sands.

The major factors which influence the salinity and ionic composition of freshwaters are the surrounding rock types, atmospheric precipitation and evaporation-precipitation processes (Gibbs 1970). The overall dominance of Na and Cl, and the proximity to the coast of the lagoons indicate that their respective ionic compositions are determined by the precipitation of airborne sea spray (Bayly 1964a, Wetzel 1975; Australian Department of Science 1978). In contrast, the relative dominance of Ca and Mg to each other is determined by the landform in which the particular lagoon occurs. Ca dominates in those lagoons found on calcareous sands (Big Waterhouse Lake, Little Waterhouse Lake, Bowlers Lagoon No 1 and No. 2). In the vicinity of these lagoons, distinct corridors of active, large, calcareous, transverse dunes lead inland from the beaches. The source of the calcareous sand is the present beaches, and the Holocene parabolic dunes. Those lagoons located on the calcareous soils also tend to be more alkaline with $HCO_3>SO_4$ than those on siliceous sands. More typical of the cation order in the lagoons of the Australian mainland and the West Coast of Tasmania, with Mg dominance over Ca (Bayly 1964a; Timms 1977; Walsh 1991), are those lagoons of Cape Naturaliste and Cape Portland, located on siliceous sands

Cape Portland No 6, on all occasions, showed K enrichment with a cation order of Na>Mg>K>Ca. This is attributed to the existence of a clay-pan, the small size of the lagoon, exposure to wind, and its shallowness (Z_r = 0.4) and constant resuspension of sediments

The main source of the major anions Cl and SO_4 is from seaspray and rainfall Some degree of sulphate enrichment noted in Cape Naturaliste No. 1 may be attributed to oxidation of sulphides and organo-sulphur compounds contained in peaty soils, evapotranspirative concentration in shallow

areas, or from burning of surrounding vegetation.

Cape Portland No 5 and No. 6 also showed relatively high levels of SO_4. It was noted that these two lagoons supported an abundant and diverse waterfowl population. The consequent nutrient enrichment (i.e. P) of the lagoons by faecal matter from the avian population was noticeable. However the lagoons were often too turbid to support algal blooms as chlorophyll values were low or not detectable, although on one occasion Cape Portland No. 6 was noted to be a distinct apple-green colour. The deposition of organic matter and subsequent incorporation into the sediments would encourage microbial activity. The sediments of these lagoons were anoxic and when disturbed released H_2S attributed to sulfate-reducing bacteria The high levels of SO_4 are attributed to oxidation of H_2S and diffusion into the water column. Constant strong winds to which the lagoons are exposed, would facilitate continual aeration of the water column, promoting microbial oxidation of H_2S and regenerates SO_4 for further microbial reduction.

The majority of wetlands were circum-neutral (pH 7.0) to alkaline (pH >7.0) and reflect the influence of the calcareous sands and their brackish nature. This is in contrast to many freshwater dune lakes of mainland Eastern Australia (Bayly 1964a; Timms 1986a) and Tasmania (Bowling *et al.* 1993) which occur on siliceous sand masses and are among the world's naturally most acidic and oligotrophic water bodies (Outridge *et al* 1989). pH values are similar to those obtained from lagoons on calcareous sands of the Bass Strait Islands (Bowling & Tyler 1984) and several lagoons (Hibbs Lagoon, Paradise Lagoon, Nye Bay Lagoon), in south west Tasmania (Bowling *et al.* 1993).

3.7.7 Dissolved Organic Carbon.

The relatively high carbon content of dune lake waters is attributed to the extent of emergent and fringing vegetation combined with surface and groundwater flows above the B soil horizon (Reeve & Fergus 1982; Wrigley *et al.* 1988) Shallow ephemeral lagoons subject to periodic drying may develop little aquatic vegetation to contribute decaying organic material. In the case of the ephemeral lagoons of Cape Portland such vegetation was non-existent Because they are located amongst active dunes, there would also be little contribution of leached material from the soil entering the lagoons. Yet Cape Portland No. 5 and No. 6, two rather shallow lagoons, had extremely high levels of DOC, particularly during the late, hot months of summer (**Appendix** 1) These levels are attributed to an organic rich anoxic sedimentary layer, the result of enrichment by waterfowl. Microbial decomposition and biogenic activity, coupled with wind-induced resuspension of sediments would encourage diffusion of organic carbon into the water.

The moderate to high DOC values of Bowlers Lagoon No. 1 and No. 2, and the Waterhouse lagoons is attributed to the extensive beds of aquatic macrophyte communities covering large portions of the respective waterbody and the fringing wetland. The decomposition of the littoral aquatic macrophytes and vegetation plus leaching of organic material from the sandy soils (Wrigley *et al.* 1988) is a major source of carbon to these lagoons.

This is in contrast to the ephemeral lagoons of Cape Naturaliste. The very high DOC and g_{440} values of these lagoons are largely attributed to the peaty substrate of the B soil horizon. Leaching of this organic material from the soil is the major source of DOC (Wrigley *et al.* 1988) for these lagoons. Temporal changes in DOC in these dune lake waters are attributed to a large allochthonous input from changes in overland flow, entering these lagoons and reinundation of

sediments.

3.7.8 Conductivity.

Conductivity (at 25 °C) is influenced by the difference between water evaporation and inflow. The shallow lagoons of the North East have very large surface areas relative to depth (Z_r), and consequently evaporate rapidly in summer, reaching high conductivities (Cape Portland lagoons - **Appendix** 1). In addition, proximity to the coast also contributes to higher conductivity via sea spray, and in the case of Cape Portland No. 3, overtopping of the shingle levee occurs during particularly severe storms, though meromixis is not thought to occur. The lagoon is so shallow (Z_{max} = 1.0 m) and exposed to prevailing winds, that any layer of seawater would soon be entrained in the overlying 'fresh' water. The intrusion of seawater into several Tasmanian lowland, riverine (King & Tyler 1981) and coastal, freshwater lakes (Bowling *et al.* 1993) with resultant meromixis, is documented.

The greatest variation in conductivity was evident in the ephemeral wetlands as these dry out during the summer. The larger permanent wetlands such as Big Waterhouse Lake only showed slight variations relative to the ephemeral lagoons The Cape Naturaliste lagoons, because they lie on a leeward shore, may possibly receive less in the way of seaspray. This may explain in part the lower conductivities experienced by this group of lagoons

3.8 SUMMARY & CONCLUSIONS.

This study, though preliminary in nature, represents the first investigation, at this level of intensity, of the physical and chemical attributes of a large group of wetlands in Tasmania and one of only a few studies in Australia. Such studies are becoming increasingly important to ensure that the ecology of plant and animal communities are preserved in habitats now recognised as of some importance. The collection of physico-chemical data has provided a quick assessment of the environmental status of the wetlands. With the biological data gathered (Chapter 4), this study will go some way to understanding wetland ecosystems and of the ecological processes within them.

As sampling was carried out at approximately three monthly intervals, a more intensive sampling program would be desirable (Chapter 5). Therefore results of this study should be considered as a reconnaissance.

Most of the lagoons are shallow and have extensive growths of submerged and emergent macrophytes. The relative amounts of plant biomass within the water column is dependent upon light penetration, and the ratio between Z_{max} and Z_{eu}. The great majority of lagoons were light restricted and this is attributed to the degree of suspended particulate matter and dissolved humic substances. Seasonal changes in conductivity due to evaporative concentration followed by dilution during rainfall were evident in the shallower wetlands. Most were brackish to saline Ionic composition was dominated by Na^+ and Cl^- The majority of lagoons were circum-neutral (pH 7.0) to alkaline (pH > 7.0) and reflect the influence of the calcareous sand, similar to lagoons on the Bass Strait Islands, but in contrast to the dystrophic lagoons of the West Coast and Bruny Island, located on vegetated and stable siliceous dune systems. The NE lagoons were too shallow and exposed to allow thermal stratification. Most of the Cape Naturaliste lagoons and associated wetlands possessed g_{440} values characteristic of moderate to ultra-dystrophic water bodies and are amongst some of the highest values recorded from Tasmanian freshwater bodies (Walsh 1991).

The lagoons of North East Tasmania could be separated into 3 groups based on limnological properties as influenced by their respective hydrological regimes.

The dune lakes of the north eastern coastal plain of Tasmania are similar in mode of origin and age to other coastal freshwater dune lakes in Tasmania However, these dune lakes differ limnologically from those coastal freshwater lakes yet investigated. They differ, in that they are more alkaline than the majority of Tasmanian and mainland Australian lagoons, and markedly astatic relative to most Tasmanian lagoons.

CHAPTER 4
THE ECOLOGY OF THE MICROCRUSTACEAN FAUNA FROM NORTH EAST TASMANIA. AUGUST 1991-SEPTEMBER 1992

4.1 ABSTRACT.

Reconnaissance of the ecology of the NE wetlands and preliminary survey of the invertebrate fauna has found microcrustacean assemblages not previously recorded in the literature and of high diversity. The lagoons of North East Tasmania can be divided into 3 groups based on their respective hydrology and to a lesser extent on their microcrustacean fauna. In some lagoons the microcrustacean assemblage present shows affinities with the saline lakes of inland Australia (e.g. Lake Eyre). The well vegetated wetlands with submerged and emergent aquatic macrophytes tend to have a significantly higher species diversity. The aquatic vegetation provides a diversity of habitats which are not available in open water. Studies on the mainland of Australia have shown seasonal drying and reinundation also contribute to species diversity. The stability of the aquatic physicochemical habitat as influenced by the hydrological regime

4.2 INTRODUCTION

The North East coastal plain of Tasmania contains many lagoons occurring within siliceous and calcareous dunes. Many are perched above the general water table in dune hollows created by wind action and sealed by organically cemented sand (Bowling *et al.* 1993). Others are surface expressions of the ground water table or shallow waterbodies impounded behind frontal dunes. Almost all are polymictic, spanning a range of nutrient states, are of variable depth and have strong seasonal trends. Physicochemically these lagoons are similar to those in temperate parts of mainland Australia and of the Bass Strait islands, being of low to moderate salinity, high acidity, moderate to high dystrophy and a seawater ionic character. Available physicochemical data are presented in Chapter 3 and in **Appendix** 1. The data show there is considerable seasonal variation in conductivity, turbidity, g440 and in DOC.

Microcrustacean zooplankton are an important component of the aquatic ecosystem in the North East wetlands, as they feed upon detritus, bacteria and phytoplankton, and in turn form a sizeable portion of the diet of higher invertebrate and vertebrate predators As they have few intrinsic regulatory mechanisms with which to counter environmental changes they are likely to be affected by habitat disturbance, both natural and man made. These naturally occurring environmental changes in the temporary and astatic waterbodies of the North East coastal wetlands and flood plains, are probably the main reason for the high species diversity and change in species assemblages recordedhere.

In contrast to those of Tasmania, the coastal lakes of the Australian mainland, especially those of south-eastern Queensland and north-eastern New South Wales, have been more comprehensively studied, and exemplify the limnology of this type of waterbody (Timms 1982, 1986a; Bayly 1961, 1964a, 1979; Bayly *et al.* 1975).

Previous work on the freshwater microfauna and flora of Tasmania has been spasmodic, piecemeal and disjointed in that it has followed the interests of individual researchers. In contrast to the dune lakes of mainland Australia (Timms 1986a), the Tasmanian dune lakes have a diverse microbiota, many of which are unique to these habitats, rare or endemic (Tyler 1992; Shiel *et al* 1989; Koste & Shiel 1987, Walsh 1991; Walsh *et al.* 1995) Generally the microcrustacean zooplankton community of Tasmanian lagoons is dominated by *Calamoecia tasmanica tasmanica* or *Calamoecia gibbosa gibbosa* (Baharuddin 1978; Walsh 1991; Bowling *et al.* 1993; Walsh *et al.* in press). Timms (1987) investigated aquatic micro-crustaceans in a brief visit to Tasmania. He found

several new and rare species, and concluded that much more research was warranted. The rotifer fauna has been investigated by Koste and Shiel (1986, 1987) and Koste *et al* (1988). Shiel *et al.* (1989) concluded that the coastal dune lakes of Ocean Beach had the highest rotifer species diversity yet recorded from Australia. The authors suggested that this is the result of a long and undisturbed evolutionary history. Tyler (1992) has found new, unique and endemic dinoflagellates in many of these coastal lagoons. A comprehensive survey (a total of 323 individual water bodies sampled) of a key group in the Tasmanian aquatic microcrustacean assemblage (Calanoida: Centropagidae) showed that many species (some endemic to Tasmania) are restricted in distribution (Walsh 1991).

4.3 STUDY SITES.

All the sites are shallow, dystrophic, astatic coastal lagoons, close to sea level and occupying deflation hollows located in siliceous and calcareous dunes. The study sites differ physically ranging from large relatively exposed lakes to small ephemeral ponds, with depths of 4 m to <0.5 m, from open water bodies to those dominated and covered by emergent macrophytes. A detailed description of sites is given in Chapter 3

Most of the lagoons have extensive growths of submerged and emergent macrophytes. The relative amounts of biomass within the water column is dependent upon light penetration, and the ratio between Z_{max} and Z_{eu}. Almost all of the dominant species of aquatic plants were emergents Most of these lagoons have extensive emergent stands of *Triglochin procera* R Br (Juncagenaceae), notably Bowlers Lagoon. Blackmans Lagoon and Big Waterhouse Lake have such stands fringing their shorelines or growing from shallow areas. Big Waterhouse Lake has an extensive flat, low-lying shoreline vegetated with *Baumea* sp , *Juncus pallidus* and *Potamogeton* sp., which is frequently inundated by a variable water level. Little Waterhouse Lake occupies a long low lying basin with extensive open water and a narrow littoral fringe occupied with *Typha sp Triglochin procera, Lepidosperma longitudinale, Juncus articulatus* (Juncaceae) and *Juncus procerus* (Juncaceae). Bowlers Lagoon is choked with *Myriophyllum simulans, Wolffia* and has extensive areas of *Eleocharis spp* and *Potamogeton spp.*

4.4 AIMS.

The aims of this part of the study were three fold:

a) To investigate the microcrustacean faunal assemblages of permanent, markedly astatic and ephemeral coastal lagoon ecosystems;

b) To determine if the North East lagoons could be grouped into permanent, markedly astatic and ephemeral coastal lagoon ecosystems based on community data;

c) To identify the key species which explain difference in community faunal assemblages between and within permanent, markedly astatic and ephemeral coastal lagoon ecosystems respectively.

4.5 METHODOLOGY.

4 5.1 Collecting.

Both biological and physicochemical samples (Chapter 3) were collected approximately at three

to four month intervals between August 1991 and September 1992 from twenty individual wetlands between Cape Naturaliste and the township of Bridport on the north east coastal plain This was mainly to provide an indication of the variation among the wetlands, largely covering a range of wetlands types over the study area. This broad scale approach indicates the potential conservation value of a wetland, as well as its current status in terms of specific criteria. However a more intensive sampling regime and/or experimental studies is required for a greater understanding of the dynamic processes occurring in a particular wetland.

4.5.2 Taxonomy

Zooplankton and phytoplankton samples were collected by single or several oblique tows in deeper lagoons and by hand-held 20 μm mesh or 200 μm mesh conical nets in the more shallow pools and lagoons. All collections were preserved in 5-10% formalin, pending identification. Nets were washed thoroughly before and after the sampling of each site in an effort to reduce the possibility of contaminants in the samples obtained.

Identification of the cladocera and copepods, and disarticulation methodology when required is discussed in greater detail in Chapter 2.

4.5.3 Data Analysis

Community data was recorded as either presence or absence of species for each of the respective lagoons Using the same groupings of lagoons as in Chapter 3, the number of taxa for each lagoon was analysed to determine if there was any difference in species richness between the three lagoons groups of permanent (P), markedly astatic (A) and ephemeral (E). Pair wise comparison of the different lagoon types A·P, A:E, and E:P were analysed by F test with SAS version 6.06.

The statistical package PRIMER was used to sort the respective sites, based on their community data, into similar classes. Refer to Chapter 2 for PRIMER details The interrelationships between sites and sampling date where then mapped in an ordination by non-metric multi-dimensional scaling (MDS), with and without the Tregaron Lagoons in an attempt to visualize the community patterns

4.6 RESULTS.

Twelve calanoid copepod species in four genera were recorded. The cladoceran fauna was also diverse with 42 species in twenty one genera represented (**Appendix** 2).

Generally the microcrustacean zooplankton community was dominated by *Calamoecia tasmanica tasmanica*, *Calamoecia gibbosa gibbosa*, *Ceriodaphnia quadrangula* s.l. or *Ceriodaphnia laticaudata* s.l.. Other species are discussed below. The littoral community was dominated by *Simocephalus vetulus*, *Chydorus* spp , *Graptoleberis testudinaria*, *Camptocercus australis* and *Dunhevedia crassa.*

Statistical analysis of community data with pair-wise comparison of lagoons groups (**Table** 4.1) showed no statistical difference in A.P and A:E in species richness or degree of variation In contrast E:P, whilst T values showed no statistical significance, F values showed there was a significant degree of variation in species composition between the two lagoon types with F = 0.0082. In short there was greater degree of variation between ephemeral and permanent lagoons than between ephemeral and astatic, and between astatic and ephemeral lagoons. There was some

indication of more variation between astatic·permanent than ephemeral:astatic. This gives an indication that the "stability" of the lagoon has a statistically significant and ecologically important role in determining species richness on a seasonal basis.

Table 4.1 Test of Significance in comparison of species richness between lagoon types.

F Value	P	A	E	T Value	P	A	E
P	-	0.1069	0.0082	P	-	0.4037	0.4674
A	-	-	0.6269	A	-	-	0.2216
E	-	-	-	E	-	-	-

Analysis of temporal community presence/absence data using all sampling dates for each site, using the Bray-Curtis similarity coefficient, resulted in three major groups and Big Waterhouse Lake (28/11/91) as an outlier (**Figure** 4.1) The later separated at the 5% level with three main groups separating at approximately 7%, roughly corresponding to the Ephemeral, Astatic and Permanent groups of lagoons. The initial groupings of sites into Ephemeral, Astatic and Permanent became somewhat blurred with the Tregaron Lagoons and Little Waterhouse Lake (28/11/91) being included in Group 2 containing predominantly Astatic lagoons, and, Blackmans Lagoon (19/8/91) and Bowlers Lagoon No. 1 included with the Ephemeral lagoons (Group 3)

The same analysis was repeated without the community data for the Tregaron Lagoon sites (**Figure** 4.2). It was hoped that this would allow greater separation of sites in the dendrogram However this had little effect with little change to the classes

MDS ordination of the temporal set of samples, with (**Figure** 4.3) and without the Tregaron Lagoons (**Figure** 4.4) was performed The graphical representation of community patterns was fuzzy with no clear delineation of sites, spatially or in time. Sites identified as Ephemeral, Astatic or Permanent also showed no discrete groupings with much overlapping of lagoon types.

The community data for each sampling occasion was then pooled into one presence/absence data set for each site, so that temporal variation in community composition was eliminated. The pooled data set for each site was then analysed using the Bray-Curtis similarity co-efficient. The resulting dendrogram, when temporal variation is not taken into account, showed three main groupings of sites which closely agreed with the Ephemeral (E), Astatic (A) or Permanent (P) lagoon types (**Figure** 4.5) The Bray Curtis dissimilarity co-efficient between the above three groupings of sites, based on presence/absence of community data was calculated using SIMPER to determine the species responsible for these lagoon groupings If a species contributes much to the dissimilarity of 2 groups it is thus a good discriminating species The Bray Curtis dissimilarity co-efficient showed the groups were highly dissimilar with average dissimilarities of 88-91% between the groups based on comparison of their community composition (**Appendix** 3). The first 8-10 species (out of a total of 54) contributed approximately 50% of the dissimilarity in comparison of the lagoon types.

The indicator species for Permanent (P) lagoons were *Daphnia carinata*, *Simocephalus vetulus*, *Boeckella symmetrica* and *Ceriodaphnia* spp Indicators for Astatic (A) were the

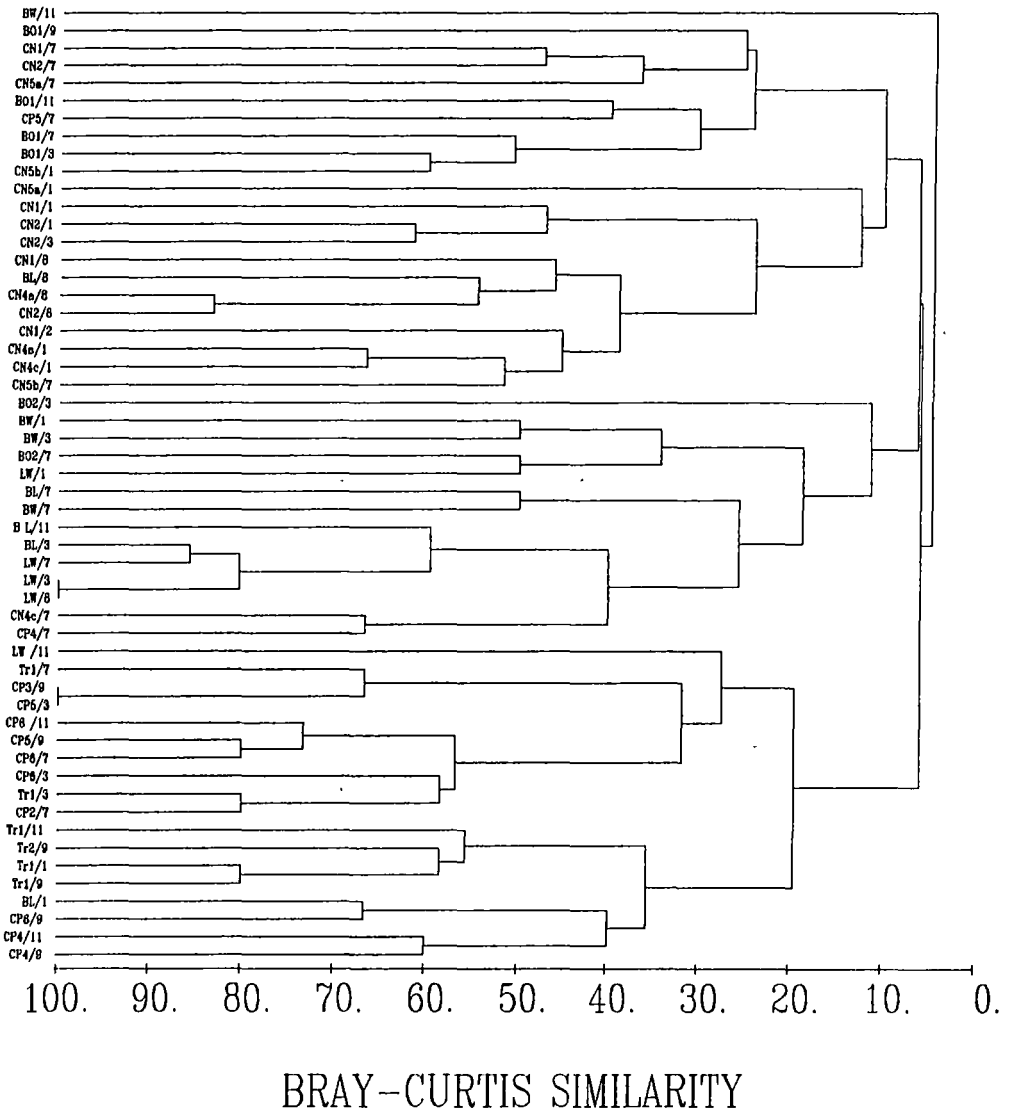


Figure 4.1 Dendrogram resulting from cluster analysis of NE Tasmanian dune lakes sampled 1991-1992. (AA/12 = Site / month of sample).

CP = Cape Portland

CN = Cape Naturaliste

BL = Blackmans Lagoon

LW = Little Waterhouse Lake

TR = Tregaron Lagoon

BW = Big Waterhouse Lake

BO = Bowlers Lagoon

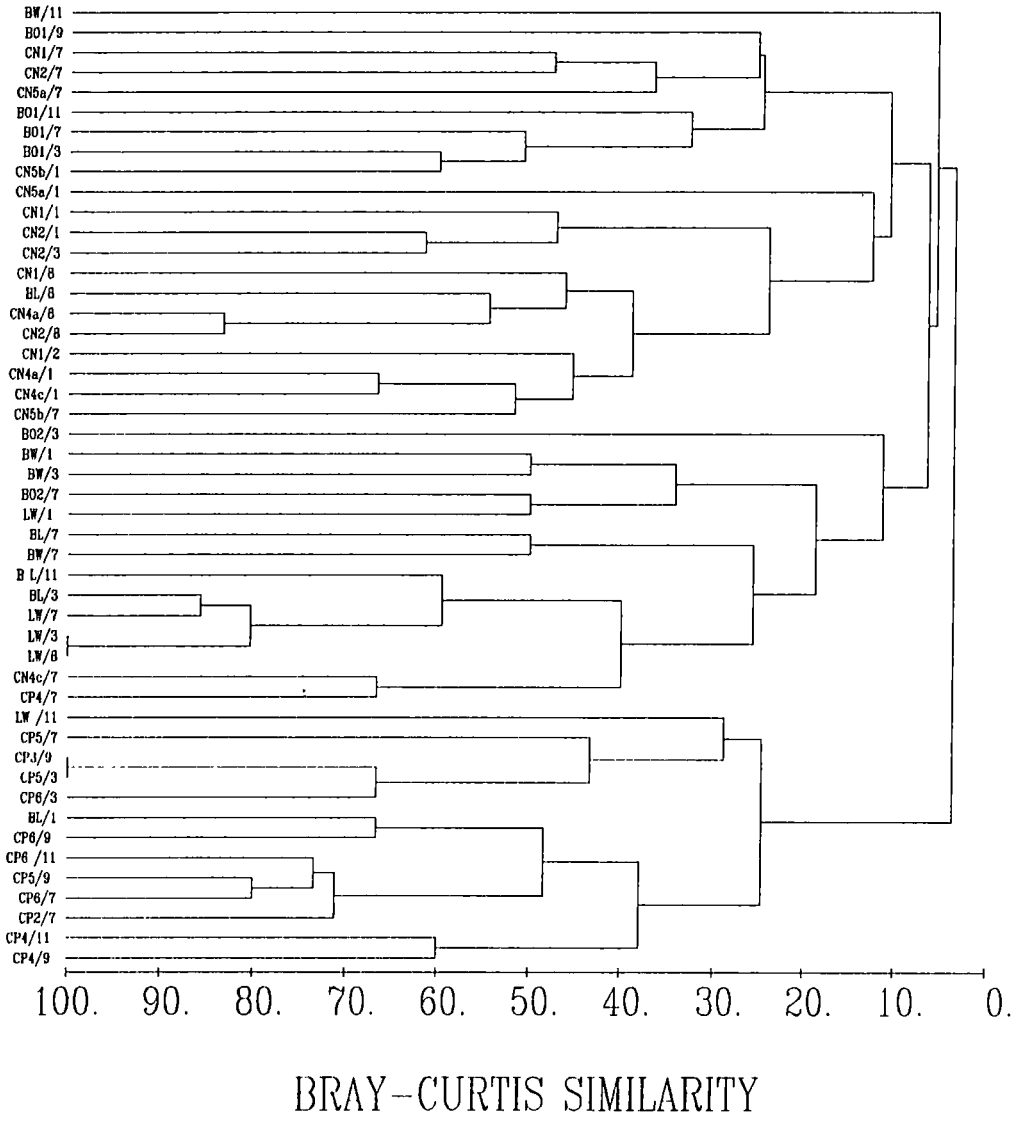


Figure 4.2 Dendrogram resulting from cluster analysis of NE Tasmanian dune lakes sampled 1991-1992. Not including Tregaron Lagoons. (AA/12 = Site / month of sample).

CP = Cape Portland

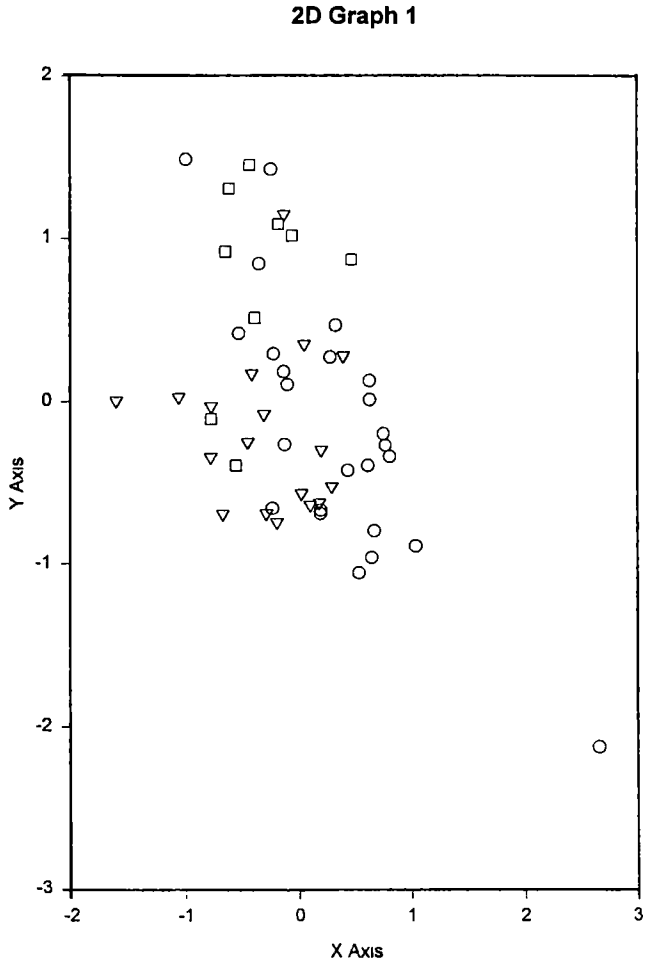
CN = Cape Naturaliste

BO = Bowlers Lagoon

LW = Little Waterhouse Lake

BW = Big Waterhouse Lake

BL = Blackmans Lagoon



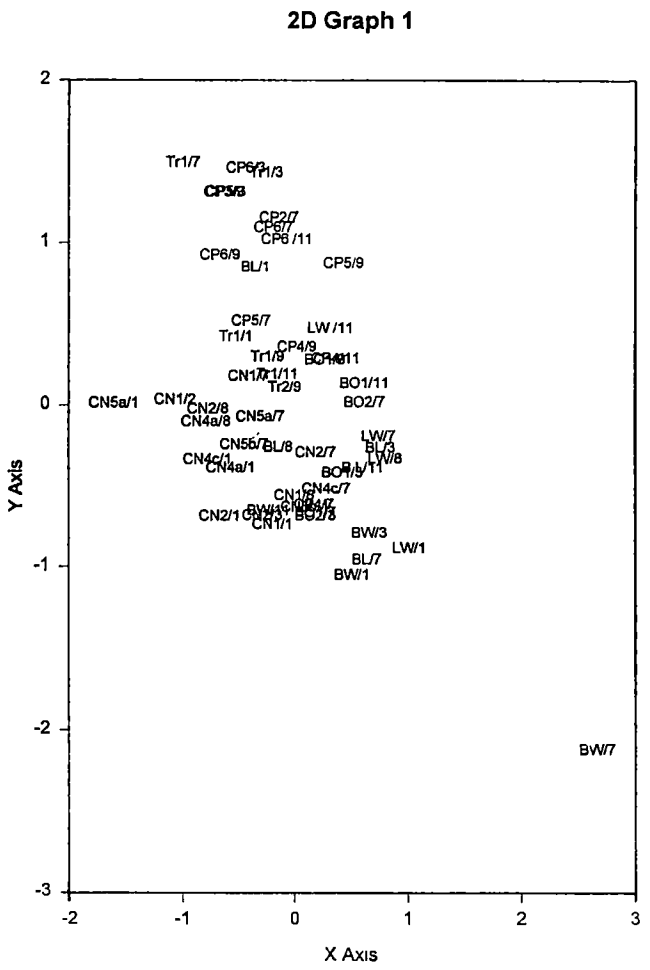


Figure 4.3 MDS ordination of NE Tasmanian dune lakes (AA/12 = Site / month of sample).

CP = Cape Portland
CN = Cape Naturaliste
BO = Bowlers Lagoon
LW = Little Waterhouse Lake
BW = Big Waterhouse Lake
BL = Blackmans Lagoon
TR = Tregaron Lagoon

□ Astatic lagoons
▽ Ephemeral lagoons
○ Permanent lagoons

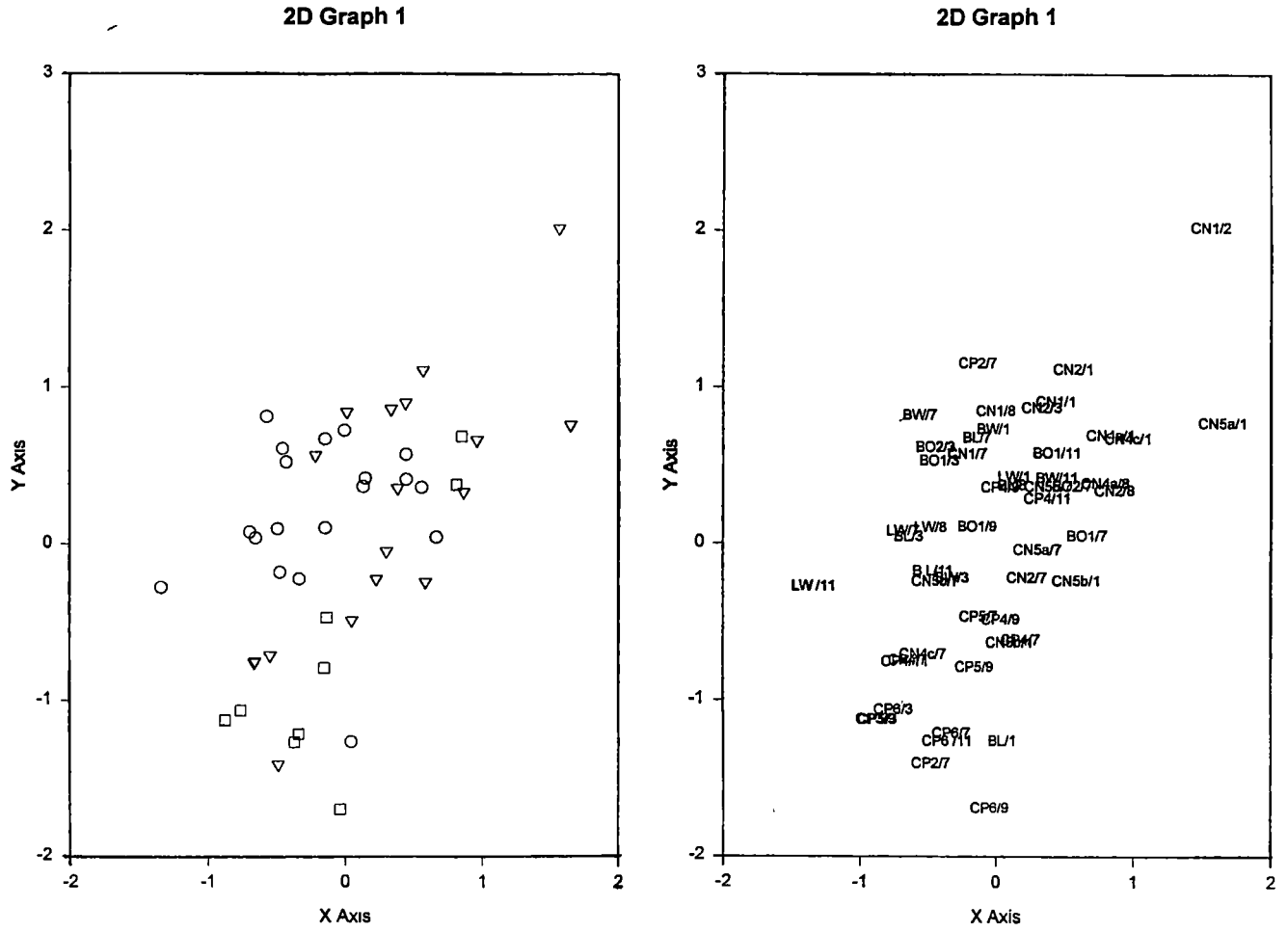


Figure 4.4 MDS ordination of NE Tasmanian dune lakes sampled 1991-1992. Not including Tregaron Lagoons. (AA/12 = Site / month of sample).

CP = Cape Portland
CN = Cape Naturaliste
BL = Blackmans Lagoon
LW = Little Waterhouse Lake
BW = Big Waterhouse Lake
BO = Bowlers Lagoon

□ Astatic lagoons
▽ Ephemeral lagoons
○ Permanent lagoons

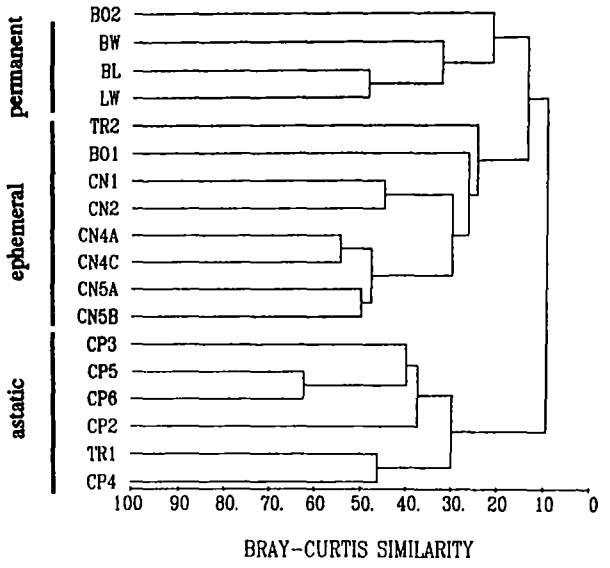


Figure 4.5 Dendrogram resulting from cluster analysis of NE Tasmanian dune lakes sampled 1991-1992. Using pooled data set for each site.
(AA/12 = Site / month of sample).
CP = Cape Portland, CN = Cape Naturaliste, BL = Blackmans Lagoon, LW = Little Waterhouse Lake, BW = Big Waterhouse Lake, TR = Tregaron Lagoon, BO = Bowlers Lagoon.

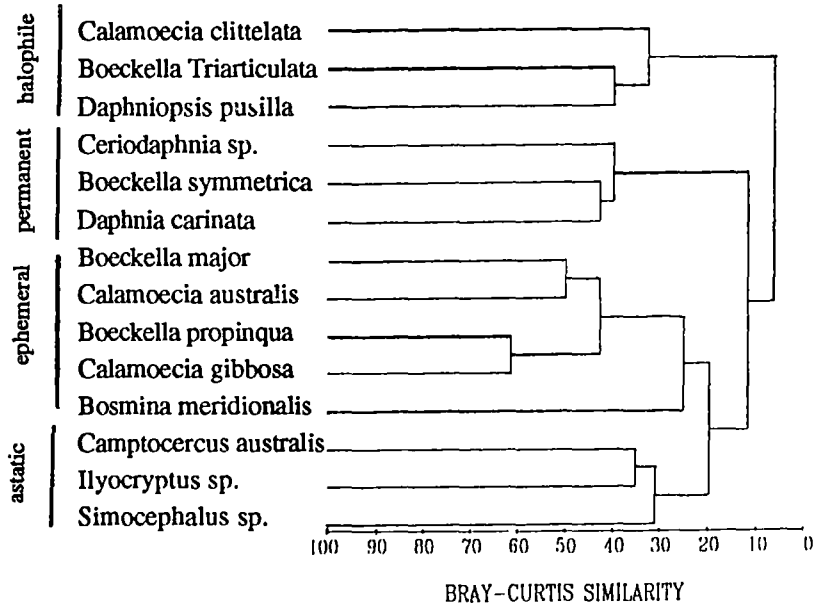


Figure 4.6 Dendrogram resulting from cluster analysis of indicator species identified by MDS for NE Tasmanian dune lakes (sampled 1991-1992).

halophilic species *Daphniopsis pusilla*, *Calamoecia clitellata* and *Boeckella triarticulata* The ephemeral lagoons were characterised by *Boeckella major*, *Boeckella propinqua*, *Calamoecia gibbossa*, *Calamoecia australis*, *Camptocercus australis*, *Ilyocryptus* sp. There was some overlap between ephemeral and permanent lagoons, in that *Simocephalus vetulus* and *Daphnia carinata* present in ephemeral lagoons, were identified as indicator species which contributed to the dissimilarity between ephemeral and astatic lagoon types

These indicator species for the three lagoon types were analysed using the Bray Curtis similarity co-efficient to group the above using species rather than sites (**Figure** 4 6). As expected the species were separated into three classes The first division at 5% were those identified as characteristic of Astatic lagoons *D. pusilla*, *B. triarticulata* and *C. clitellata.* The division of the ephemeral and permanent indicator species occurred at 10% level, which in general, confirmed the species groupings. The exception being *Simocephalus vetulus* which was included in amongst the ephemeral lagoon indicator species. The separation of the cladoceran and copepods into subgroups within the ephemeral group at the 20% level was of interest.

4.7 DISCUSSION.

4.7.1 Cladocera

Ilyocryptus cf. *spinifer* was present in most of the lagoons with extensive macrophyte communities. This species is a non-swimming sedentary, crawling and burrowing animal (Fryer 1974). *Ilyocryptus* cf. *spinifer* was also present (at low relative abundances) in numerous open water samples from many of the lagoons of Cape Naturaliste. This is in keeping with the observations of Fryer (1980), who considered it to be a benthic species and tolerant of a wide pH range (3 5-8.5). The daphniid species *Simocephalus vetulus* in comparison was a common species. *Simocephalus* though not numerically abundant, often formed a significant component of the zooplankton sample.

Species of the daphnid genus *Ceriodaphnia* (*C. quadrangula* s.l. and *C. laticaudata* s l) were found in those water bodies that experienced little change in water depth, relative to the more temporary lagoons (e.g. Bowlers, Blackmans and Little Waterhouse Lagoons) These species are variable in seasonal abundance and presence on the Australian mainland (Smirnov & Timms 1983). This appears to be the case in Tasmania with the genus mainly present in winter in permanent lagoons and, during or just following the 'filling phase' of markedly astatic lagoons.

The daphniid *Daphnia carinata* s.l., like *Ceriodaphnia*, appears to favour the relatively more stable environments of the permanent waterbodies. It is present throughout the cooler months of the year in those lagoons from which it was recorded. This is in keeping with records from the mainland where populations die out during the warmer temperatures of summer (Smirnov & Timms 1983). The shallow lagoons of the north eastern wetlands contract via evaporation during summer, with a reduced volume of water to heat, the lagoons experience high water temperatures (in excess of 25°C). This species survives in the respective water bodies as a sexually produced egg encased in an ephippium. This 'resting stage' hatches when more favourable cooler conditions are present.

Daphniopsis pusilla, a halophile daphniid, is found in the relatively more saline lagoons of Cape Portland, were it is the dominant planktonic animal and found in bloom conditions The shallow lagoons fluctuate greatly in salinity, from slightly saline to concentrations 50% that of seawater. This encompasses the optimum range for this species (Sergeev & Williams 1983). A

further factor that influences the number of animals found is the bloom of filamentous algae that was noted. The colour of the water in Cape Portland No. 6 on two separate occasions was that of a green apple. These shallow waters, heated rapidly by midday temperatures, the constant resuspension of sediments and subsequent release of nutrients from them due to exposure to the constant coastal sea breeze, plus the organic enrichment of these lagoons from the large water fowl populations present, together combine to form conditions suitable for such blooms to occur. Such algal blooms would support the large numbers of *Daphniopsis pusilla* and *Boeckella triarticulata.*

The Macrothricid *Neothrix armata* is a benthic animal and feeds on organic particles up to a quarter of its body length. It is not a filter feeder but mechanically handles its food with limbs I and II (Fryer 1974). The carapace surface is covered with bristles and these are believed to keep the organic particles off the body surface. *Neothrix armata* has previously been collected from Tasmanian dystrophic waters (Dr. R. Shiel, Murray Darling Freshwater Research Centre, pers comm) and is probably more widespread than present records indicate.

Moina australiensis is a euryhaline species recorded from fresh to brackish waters. Believed to be widespread on mainland Australia with records from W.A , Qld, and Victoria (Smirnov & Timms 1983). This is the first record for Tasmania and though only recorded once from Cape Naturaliste No. 5a, it is probably to be found in coastal wetlands along eastern Tasmanian.

4.7.2 Copepoda

Calamoecia tasmanica tasmanica. The species is relatively widespread in Tasmania with an essentially coastal and western distribution. The distribution of this species falls within the western and coastal provinces of Bowling (1988). It was recorded intermittently from several of the C Naturaliste sites and also from the Pig and Whistle Reservoir near Gladstone. The waters preferred by this species have ionic proportions similar to World Average Sea Water (WASW)(Walsh 1991). Waters were typically low in calcium, magnesium, bicarbonate and sulphate, relative to the other ions. Departures from WASW proportion are attributed to the astatic nature of the coastal lagoons and close proximity to the sea. The dystrophic nature of the lagoons and inland waters occupied by this species is indicated by the average g440 value of 16.590 m^{-1}, and the range of results obtained. Turbidity was normally low, with only exposed coastal sites displaying high values.

Calamoecia australis. This species has been recorded from only ten sites in Tasmania prior to this study (Walsh 1991), with a dispersed distribution, two of which have since been inundated by L. Pedder (nova). Apart from L. Pedder and L. Gordon, in south west Tasmania, *Calamoecia australis* is found mostly in shallow quite highly coloured coastal lagoons. pH values varied from acidic to alkaline. Turbidity values were low to moderate. g440 values obtained in this study indicate the dystrophic conditions this calanoid may tolerate. Previous studies showed this species favoured waters of low conductivity (Walsh 1991). However in this study *C. australis* was recorded from lagoons of moderate values, such as Big Waterhouse Lake and Walsh (1991) recorded it from D' Arcys Lagoon, Bruny Is. A lagoon of variable but high conductivity. This calanoid favours waters with ionic proportions approaching WASW, high in sodium and magnesium and with low calcium content. The anions present a similar situation, though high bicarbonate values were recorded from Big Waterhouse Lake.

Calamoecia gibbosa gibbosa. The distribution of this species is restricted to the east of Tasmania Walsh (1991) recorded this species in samples from coastal lagoons and inland,

permanent astatic lagoons. It was the most commonly recorded and widely distributed calanoid copepod in that survey. This species tends to favour circum-neutral to basic pH values (pH 6.5-8.5), with the lowest for C. Naturaliste No. 1 and No. 4a, and the highest Tregaron No. 1 (pH 8.4). Turbidity values were in general low to moderate with most lagoons in which *C. gibbosa gibbosa* was found below 4.00 NTU. Values for g440 varied, indicating the differences between the dissolved organic content of the lagoons of north eastern Tasmania. Values fell into a low/moderate grouping, and then there were those lakes of C Naturaliste with extreme dystrophic conditions (21.072 to 50.000 m^{-1}). K_{25} and ionic values varied according to proximity to the sea, the astatic nature of the water body and prevailing wind. **Figure** 3.6 showed that ionic proportions for the cations approached WASW. The anions were more varied, but in most lakes had relatively high sulphate values.

Boeckella symmetrica is a common species on the Australian mainland and also widely distributed in Tasmania Typically it is associated with small turbid farm dams and reservoirs Distribution is mainly restricted to eastern Tasmania (Walsh 1991). Values for pH were in the main circum-neutral to alkaline. This species tolerates moderate dystrophic waters as indicated by the g440 values. K25 values indicated that the waters were relatively high in electrolytes, indicating a higher salinity tolerance range for the species. Previous studies (Walsh 1991) indicate the species prefers high proportions of the cation magnesium and moderate levels of calcium. Anions tend to vary more, with a diverse range of relative proportions shown. Walsh (1991) found *B. symmetrica* tolerant of relatively great range of turbidity, ranging from clear to highly turbid (0.50-100 NTU)

Boeckella triarticulata. This copepod species occurred in most of the Cape Portland sites sampled. In these lagoons *B. triarticulata* was the dominant planktonic copepod, present in 'bloom' numbers. The pH range was relatively narrow, with mainly basic to circum-neutral values. Turbidity was low to moderate, with the lowest value of 0 4 NTU recorded for C Portland No 4 and the highest of 70.00 NTU for C. Portland No. 5. K_{25} and ionic values varied considerably, reflecting the seasonal and ephemeral nature of these shallow hyposaline coastal lagoons

Boeckella nyoraensis. This is a rare species, first found in 1912 by Searle (Bayly 1964b, 1979) and recorded only three times since, in a coastal lagoon on the south eastern Australian mainland (Timms, 1977) and from D'Arcy's lagoon (Bruny Is.) by Baharrudin (1978), and found in a series of four coastal lagoons on Bruny Island (Walsh 1991). *B. nyoraensis* was found in C. Naturaliste No. 5a, and is most likely prevalent in other lagoons in the immediate vicinity. I believe it is seasonal in its presence and is probably more widespread in its distribution along the coastal environs of Tasmania and South East Australia. However only with more intensive and frequent sampling, covering a wider area will this be proved. *Boeckella nyoraensis* is a large copepod measuring up to 3-4 mm. Its large size and relative low numbers are attributed to it being a carnivore. An interesting thing noted was that the extremely high proportion of females to male *B. nyoraensis* identified (60:1). Identification was verified by (Dr. I. A E. Bayly, Monash University, pers. com.).

Boeckella major is a large copepod measuring up to 5 mm in extreme cases. Its large size and relative low numbers are attributed to it being a carnivore, preying on other copepods, cladocerans and rotifers (Green & Shiel 1995). *Boeckella major* is typically found in small temporary waterbodies, explaining its presence in the C. Naturaliste lagoons that experience periodic drying and/or large changes in volume. The only record for Tasmania prior to this study was a roadside pool at Mienna, Great Lake.

4.7.3 General Discussion

To the best of the my knowledge there have been few previous studies (Brehm 1953) in North East Tasmania concentrating upon aquatic microcrustacea.

The microcrustacean species (especially cladocerans) occurring on the North East wetlands flood plain form a rich assemblage in comparison to other studied areas of Australia This may, in part, be due to the relatively few studies carried out on the littoral Entomostraca in Australia For example, Smirnov & Timms (1983) recorded up to 10 cladoceran species per billabong from the Goulburn billabongs, while Shiel (1976), in a more detailed study of one of the billabongs, recorded 31 cladoceran species. Nevertheless, the 42 cladoceran species and 12 calanoid copepod species identified from the North East wetlands constitute a rich assemblage of species, the copepods in particular forming one of the richest so far investigated in Australia (Dr. I A. E. Bayly, Monash Uni., pers. comm.).

The majority of microcrustacean species found in this study occurred among aquatic macrophyte weedbeds. 42 cladoceran species (from 21 genera), 12 calanoid copepod species and a number of unidentified amphipod, ostracod, cyclopoid and harpacticoid species were found in weedbeds. Besides housing the rare copepod, *B. nyoraensis*, the north east lagoons are rich sites for other species and thus are significant lagoons, similar to those in the Western Tasmanian World Heritage Area, Fraser and Morton Islands. Much has been made of the ecological significance of the lake districts of Fraser Is. (Bayly 1964a; Bayly *et al* 1975; Arthington *et al.* 1986); and Stradbroke Is. (Bensink & Burton 1975; Lee-Manwar *et al.* 1980) and their associated biota.

This species richness may be influenced by the marked seasonal variation in the aquatic environment brought about by the seasonal climate. The expansion of the aquatic environment in the "Wet" season with the associated proliferation of aquatic macrophytes, creates an extensive range of physical sites that can be exploited by littoral microcrustaceans. The wide variation in the morphology of various macrophyte species (compare *Eleocharis* spp. or *Triglochin* spp with *Myriophyllum* or *Potamogeton* spp.), along with differences in physical factors (eg. exposure to different turbidity, different water depths, etc.), provides a variety of sites and microhabitats to suit different microcrustacean species (Pennak 1966; Campbell & Clark 1983; Irvine *et al.* 1990).

As the "Dry" season progresses and water levels fall, many littoral weedbeds die back, and hence there is a reduction in suitable habitats for littoral microcrustaceans. This was noted particularly in Bowlers Lagoon No. 1, Cape Naturaliste lagoons and in Little Waterhouse Lake. Water levels of the ephemeral and astatic lagoons fluctuate considerably and as a result shorelines are rather indefinite, dependent upon season and severity of the summer. Water levels are determined by rainfall-evaporation relationships and the internal seepage patterns of the lagoon basin and catchment. It is the exposure and reinundation of the littoral fringes and shallows of these astatic-ephemeral lagoons that allows most disturbance to the stability of the habitats. In this, these lagoons fit the model of the Intermediate Disturbance Hypothesis (Connell 1978) Periodic disturbance, in this case exposure and reinundation of the littoral fringes and shallows, enhances the number of coexisting species.

The microcrustacean population densities observed in situ in this study should be treated with caution. The variation in population densities between samples from different weedbeds and the lack of truly quantitative sampling of limnetic microcrustaceans, limit the value of the observations obtained. They do seem to indicate though, that littoral microcrustaceans attain higher densities than

do limnetic microcrustaceans. The abundant epiphytic growth in the weedbeds is likely to be a significant source of food for littoral microcrustaceans, as is fine particulate organic matter released from decomposing macrophytes.

The availability of suitable food and habitat is of major importance in determining the presence and population densities of microcrustaceans. Tait (1982) states that particulate organic matter is the major food source for microcrustaceans in the open water areas of billabongs in wetlands.

Dissolved organic carbon and phytoplankton levels are lowest in the Wet to Early-dry season and build up with the progression of the Dry season (Morley 1981). Food may be a limiting factor for open water microcrustaceans in the early part of the Dry season even after water flow has ceased, though a further study would be required to determine this definitely

Various open water species have been noted to have optimal food particle size preferences For example, the filter feeders *Moina micrura* and *Bosminopsis deitersi* prefer smaller sized food particles than does *Diaphanosoma excisum* or the raptorial feeding *Diaptomus lumholtzi* (Hutchinson 1967; Smirnov & Timms 1983). Generally calanoids are selective raptorial feeders whereas cladocerans are more general in diet.

It is likely that the diversity of microhabitats and food sources occurring within the weed bed habitats contributes to the species richness of microcrustacean communities in the study area. Shiel (1976) discusses the concept of spatial microhabitat separation, where microcrustacean species are restricted to localised areas of a weedbed habitat or to particular weedbeds because of their differing food requirements, or because of their ability to move over or through a particular substrate. This is reflected in the highly variable morphology of cladocerans (compared with copepods) which can be considered to be adaptations to a particular life mode For example, Fryer (1968) has observed that *Graptoleberis testudinaria* has the ability to glide over the smooth and slippery surfaces of various macrophytes, consuming small particles and bacteria, while *Biapertura kendallensis* ingests large inorganic particles, diatoms and algae predominantly from the bottom layers, climbing up through the vegetation only occasionally *Ilyocryptus* and *Leydigia* are detritus feeders inhabiting the surface layers of mud (Shiel 1976; Hutchinson 1967). *Macrothrix* is also a detritus feeder (Shiel 1976). *Pseudochydorus globosus* is found particularly amongst littoral macrophytic vegetation. This species is a scavenger (Fryer 1968), feeding on the remains of larger animals, and usually occurs in low numbers. Considerably more research would be required before detailed accounts could be given for the majority of species occurring in the North East wetlands

Deficiencies in the sampling of the program among aquatic macrophytes, i.e. the lack of short interval (weekly, fortnightly or at least monthly) sampling, created limitations in the description of littoral microcrustacean population dynamics. It is felt that the number of species obtained is an under representation of the true number present in the wetlands With more frequent sampling (i.e shorter intervals between sampling) of both the littoral and limnetic zones and use of different sampling methods, a greater number of microcrustacean species will be identified from individual water bodies and the wetlands as a whole. Also a more true picture of species seasonality, species assemblages and dynamics would emerge.

4.8 CONCLUSIONS

Fifty four microcrustacean taxa were recorded from the NE lagoons. The microcrustacean species (especially the Copepoda) occurring within the coastal wetland of the North East Coastal

plain form a very rich assemblage in comparison with those of other areas of Australia. This is probably due to the marked seasonal variation in the aquatic environment of this region brought about by the winter rainfall maximum. Approximately 80% of annual rainfall falls in a three to four month period. The hydrological regime is similar to the "Wet and Dry" of topical monsoonal North Australia. The expansion of the aquatic environment in the "Wet season", with the associated proliferation of aquatic macrophytes, creates a wide range of physical habitats for littoral microcrustaceans. 30 cladoceran species and 4 copepod species were from littoral habitats. Common littoral species included *Ilyocryptus* cf *spinifer*, *Camptocercus australis*, *Dunhevedia crassa*, and *Chydorus* spp..

As water levels fall with the progression of the summer "Dry season", weedbeds decline and lagoons and other waterbodies contract or dry out on the coastal plains. Littoral species assemblages decline because of lack of suitable habitats, and open water species assemblages reform after cessation of the high water flow rates of the "Wet" season. A reduction in species was evident towards the end of the "Dry" season, particularly in smaller water bodies, where deterioration in water quality was more marked as they dried up.

In view of their likely importance to the aquatic system of coastal wetlands, further investigation of both limnetic and littoral microcrustaceans is required to provide more detailed information of seasonal population dynamics and statistically verifiable population density estimates. Investigation of differences in the littoral microcrustacean species assemblages between weedbeds of different macrophyte species would also provide an overall view of littoral microcrustacean populations in coastal wetland and in flood plain areas.

As sampling was carried out at approximately three monthly intervals, a more intensive sampling program would be more desirable, particularly amongst the macrophyte beds. Cladocerans and copepods have short life spans, particularly during the warmer summer months, hence fortnightly or monthly sampling would more accurately describe species assemblages and population dynamics Furthermore, zooplankton populations are neither uniformly nor randomly distributed in a temporal or spatial sense (Hutchinson 1967), therefore difficulties arise in obtaining representative samples from a body of water. A phenomenon known as zooplankton patchiness (George 1981) may occur in the horizontal plane whereas vertical migration may cause zooplankton to accumulate at particular depths. Therefore results of this study should be considered to be broad outlines only, i.e. a reconnaissance.

In an attempt to overcome this, six lagoons were chosen, including permanent and ephemeral lagoons to study in greater detail. These lagoons were sampled monthly for approximately 12 months. It was hoped that with more frequent sampling and the use of different sampling techniques, a greater number of microcrustacean species would be identified from individual lagoons. Also a more true picture of species seasonality, species assemblages and dynamics would emerge.

CHAPTER 5
SEASONAL & DIURNAL LIMNOLOGY OF 5 NORTH EAST LAGOONS

5.1 ABSTRACT

The seasonal limnological character of coastal freshwater dune lakes in North East Tasmania is dependant upon individual lagoons water level fluctuations in responses to local and regional rainfall. The magnitude of these fluctuations is influenced by the timing and volume of winter rains. Lagoon morphometry, relative depth and surface area, coupled with duration and severity of hot dry summers and cool wet winters influence the physicochemical character of freshwater dune lakes The annual sequence of seasonal change is predictable, only the length of the wet and dry seasons varies. In this the North East lagoons are similar to those from the Swan Coastal Plain, Western Australia.

5.2 INTRODUCTION

The North East coastal plain of Tasmania contains many dune lakes occurring on siliceous and calcareous dunes All are polymictic, span a range of nutrient states, are of variable depth and show strong seasonal trends.

To date, research on coastal freshwater dune lakes has concentrated on short term studies, often based on a single visit. Bowling *et al* (1993) believed that a lagoon found to be acidic and dystrophic on the first visit would remain so. However many of the North East coastal lagoons are ephemeral, or at least extremely variable in depth. The majority are shallow, so small changes in depth are matched with relatively large changes in surface area and volume. Deeper and larger dune lakes, such as the Waterhouse lakes, Bowlers Lagoon No 1 and Blackmans Lagoon, may persist for decades. However even these lagoons display some change in surface area and volume

Water level fluctuations in the North East lagoons are considerable, and are attributed to the strongly seasonal climate. There is a distinct summer "Dry" and a winter "Wet". Close to 80% of yearly rainfall occurs in the winter months May to September (**Figure** 3 2). Many of the shallow lagoons, i.e. those of Cape Naturaliste and Cape Portland, dry out each summer. As these lagoons wax or wane in volume there is a corresponding change in the physicochemical character of the lagoons. The degree of change dependant upon depth and surface area of the lagoon. The shallower the lagoon basin the greater the change in volume as the lagoon fills or dries, and the greater the change in physicochemical character by dilution as the lagoon fills or evapoconcentration of solutes as the lagoon dries.

The physicochemical character of individual lagoons is therefore diurnally and seasonally variable (Walker & Tyler 1984; Townley *et al.* 1993; Froend *et al.* 1993; Balla & Davis 1993, Davis *et al.* 1993; Walsh *et al.* in press).

As sampling was carried out at approximately three monthly intervals (Chapter 3), a more intensive and frequent sampling program was undertaken to characterise this diurnal and seasonal variability of lagoons.

5.3 AIMS

The aims of this part of the study were twofold:

a) To investigate the seasonal and diurnal physical and chemical aquatic environment of permanent, and ephemeral coastal lagoon ecosystems;

b) To compare the degree of change in physical and chemical parameters within and between seasonally ephemeral and permanent lagoons respectively

Particular attention was focused on the role of the hydrological regime of permanent and seasonally ephemeral lagoons.

5.4 STUDY SITES.

Four permanent and two ephemeral lagoons were selected to be investigated on a monthly basis for 12 months. One of the ephemeral lagoons Cape Naturaliste No. 2 was abandoned after 3 months due to difficulty in access and logistics. The remaining five lagoons studied lie on the relatively extensive, sandy coastal plain on the North East of Tasmania (**Figure** 3. 1). The study sites Bowlers Lagoon No. 1, Big Waterhouse Lake , Little Waterhouse Lake, and Blackmans Lagoon have been described in detail in Chapter 3. Essentially these are permanent lagoons displaying relatively little seasonal amplitude in their hydrological and physicochemical regimes.

Cape Naturaliste No. 1, lies 100 m from the sea behind a single foredune The predominant catchment vegetation is of low coastal heath. The lagoon is only 2 m above sea level and fits the description of Timms' (1982) "type ii lowland lakes". The lagoon is seasonally ephemeral, shrinking to a few small muddy pools in summer, and in some years may dry out completely. There are few aquatic macrophytes, and these are located in the centre and deepest part of the lagoon basin, where small pools of water may persist.

5.5 METHODS.

An accurate assessment of depth of each lagoon was made Datum points, one metre in height and graduated in 1 cm intervals, were established on each of the five lagoons to measure rise and fall in water level Rainfall data was obtained from the Bureau of Meteorology for weather stations closest to the lagoons. This will allow correlation of changes in physicochemical parameters with waterlevel. Sampling frequency will cover seasonal variations and be not more than one months interval (preferably less)

Physicochemical and major nutrient samples were collected approximately at four to five week intervals between November 1993 and October 1994 from five lagoons. These included the ephemeral Cape Naturaliste No. 1, and the permanent lagoons Bowlers Lagoon No. 1, the Waterhouse lakes and Blackmans Lagoon. Monitoring of the limnology of the lagoons on a monthly basis included pH, turbidity, temperature, g440, conductivity (K_{25}), the major dissolved ions, in addition to dissolved oxygen, phosphate and nitrate/nitrite measurements. This intensive scale approach was mainly to provide an indication of the variation within and between ephemeral and permanent lagoons for North East Tasmania. The great variation in seasonal fluctuations in water level with changes in solute concentrations have important ecological implications, especially at the extremes of concentrations. Monitoring on a monthly basis will provide a much greater resolution of the seasonal changes in physicochemical parameters. A detailed description of methods used is given in Chapter 2.

Water temperature was measured in the shallows near the shoreline at approximately 10 cm depth, then again deeper in the lagoon, at 0 5 m depending on the depth of the respective lagoon at time of sampling. Measurements were taken at the same sampling stations on each visit The site of the depth gauge was used for the deeper water temperature measurements.

On two separate occasions Cape Naturaliste No. 1 was sampled diurnally for pH, Temperature

Site	pH	K25 uS/cm	Tn (NTU)	g440	Na	K	Ca	Mg	Cl	HCO3	SO4	DOC	Chl'a'
Big Waterhouse	7.80	745.64	1.14	7.85	81.57	4.40	24.50	15.56	132.21	53.11	41.86	22.59	1.85
Blackmans Lagoon	8.24	2316.31	0.82	3.81	347.31	13.45	46.00	63.38	622.62	169.52	61.08	31.95	2.27
Bowler's No. 1	7.33	1350.15	2.27	4.32	171.85	8.01	46.54	35.46	288.69	165.98	31.60	21.85	2.62
Cape Naturaliste No. 1	6.55	1468.38	1.21	19.13	245.00	8.88	13.17	30.92	451.31	10.82	37.85	34.05	2.03
Cape Naturaliste No. 2	5.67	811.33	1.00	38.40	126.67	4.87	20.87	21.33	248.33	144.33	26.33	32.33	8.03
Little Waterhouse	8.11	2100.07	0.89	3.95	312.64	8.09	57.00	56.00	530.00	156.93	88.29	29.89	1.12

Table 5.1 Mean values for physicochemical parameters of NE Tasmanian lagoons.

(^{o}C), K_{25} and DO_2. On one of these occasions the lagoon was sampled with 2 hourly measurements for chlorophyll a, nitrate, nitrite, ammonia and PO_4. Analysis of the major nutrients was performed on a Hach DR/2000 in the field to look at diurnal processes of this shallow lagoon.

Principal Components Analysis (PCA) was carried out on the physicochemical data for the above five lagoons, including what data was recorded for Cape Naturaliste No. 2, as per Chapter 2 and 3.

5.6 RESULTS

Rainfall data from three meteorological stations close to the lagoons was obtained and monthly totals plotted (**Figure** 5.1). There was a distinct peak (250 mm) between November and December for the three meteorological stations, followed by a pronounced trough (<50 mm) for the "dry months" of January to April. During May there was another small peak in rainfall, and this was then followed by a return to monthly rainfall totals of below average rainfall of <50 mm.

5 6.1 Hydrology

The depth of each lagoon was recorded on each sampling occasion (**Figure** 5.2). All lagoons showed a steady decline in water levels from an original "high" during the passage of summer, then a slight rise in depth over the winter months, followed by a decline again during the following summer months.

Blackmans Lagoon showed a pronounced decline in depth relative to the other lagoons towards the onset of the second summer that data was obtained.

Cape Naturaliste No. 1 was dry except for a small shallow pool when sampled 6/4/94-2/6/94. The depth gauge was completely exposed and surrounded by dry sediment on 5/5/94. Z_{max} for Cape Naturaliste No. 1 was approximately 0.5 m

Data for Big Waterhouse Lake was not obtained beyond 1/9/94 due to the removal of the datum point by persons unknown However water levels may be approximated by comparison with Little Waterhouse Lake and Bowlers Lagoon.

5.6.2 Physicochemical Results

Limnological conditions are summarised in **Table** 5.1 and in **Appendix** 4. The shallowness of the lagoons, large surface area relative to depth, and exposure to frequent strong winds ensures long term thermal stratification is unlikely. However on a number of occasions water temperatures measured in the shallows of lagoons differed considerably from those measurements made deeper and away from the shoreline **Appendix** 5.

The highest water temperature recorded was in Cape Naturaliste No. 2 (29.8^{o} C) and the coldest in Bowlers Lagoon (2 9^{o} C). Spatial variation in temperature was also highest in Cape Naturaliste No. 1 and No. 2 during summer, and in Bowlers Lagoon during winter. Seasonal variation was greatest in Cape Naturaliste No 1 and also in Bowlers lagoon. The least variable lagoon both seasonally and spatially was Blackmans Lagoon, with little relative difference between the shallows and deeper portions of the lagoon.

The g_{440} values for individual lagoons showed moderate (g_{440}=1<5.0 m^{-1}) to extreme dystrophy (g_{440}=>25 0 m^{-1}) or "blackwater". The ephemeral lagoon Cape Naturaliste No. 2 showed extreme dystrophy on all occasions it was sampled, as did Cape Naturaliste No. 1 on three

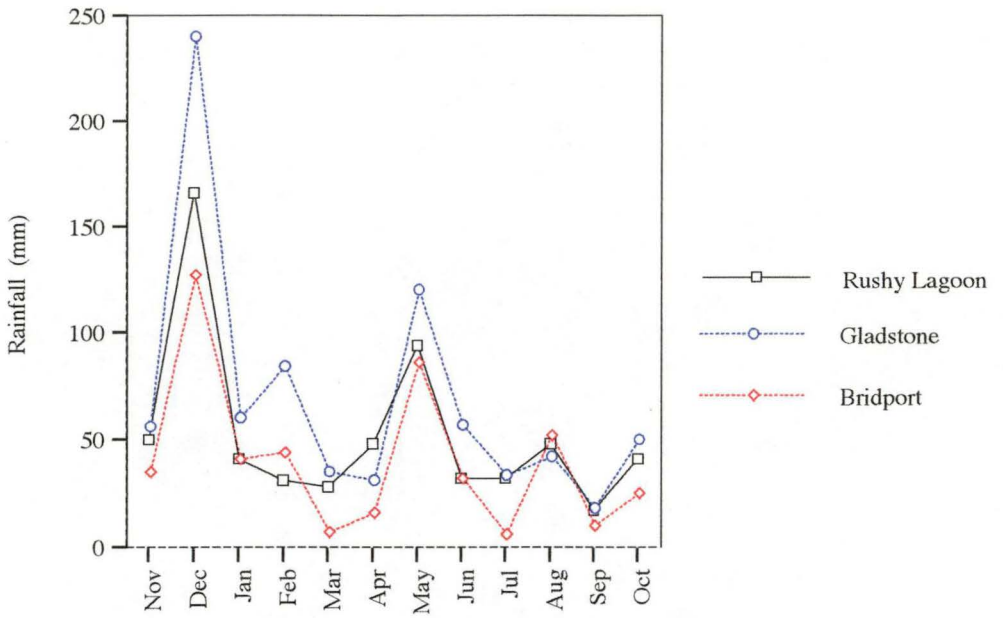


Figure 5.1 Monthly Total Rainfall for the period Nov.1993-Oct.1994.
North East Tasmania. Bureau of Meteorology.

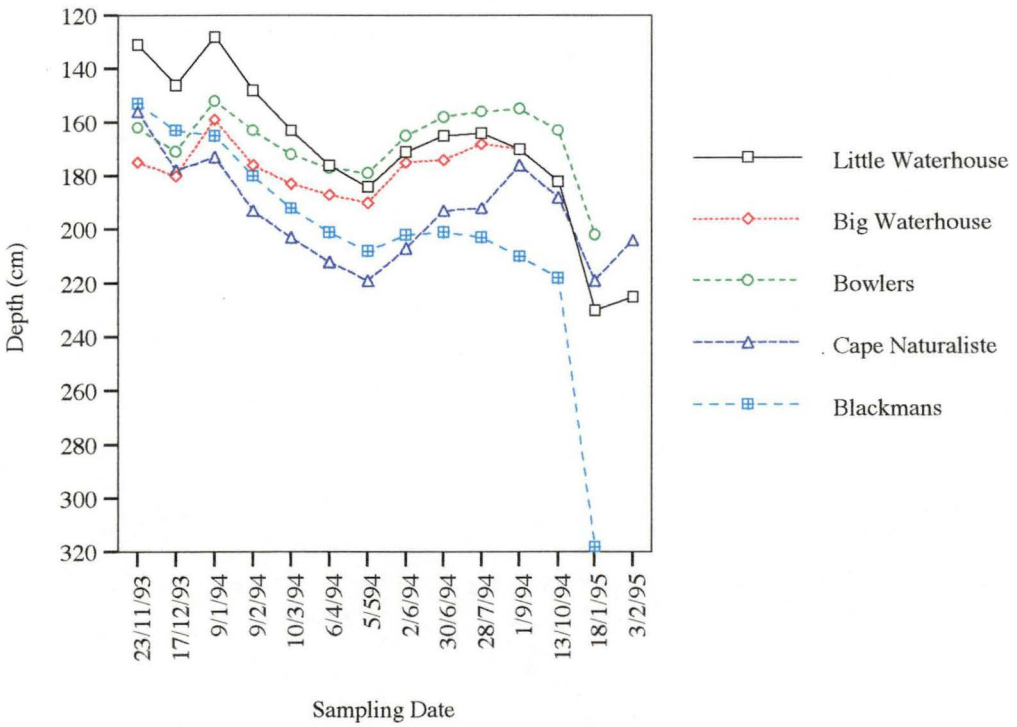


Figure 5.2 Water surface levels for each of the five NE Tasmanian lagoons sampled monthly Nov.1993-Oct.1994

NB: Depth gauge measured in 1 cm increments from 100 to 200 cm. Lake surface levels below 200 cm measured using a plumb line and spirit level.

separate occasions. On all other sampling dates Cape Naturaliste No. 1 was highly dystrophic with g_{440} values 10-25.0 m^{-1}. In comparison the permanent lagoons; Little Waterhouse Lake, Blackmans Lagoon and Bowlers Lagoon were relatively constant with moderate dystrophy. Blackmans Lagoon showed little temporal variation in g_{440}, as did Bowlers Lagoon except on one occasion had a value of 10.0 m^{-1}. Big Waterhouse Lake displayed a significant degree of temporal variation in dystrophy ranging from moderate to high dystrophy

pH values for the permanent lagoons Big Waterhouse Lake, Little Waterhouse Lake, Bowlers Lagoon and Blackmans Lagoon, are circum-neutral to alkaline, predominantly between pH 7.0-9.0 reflecting the brackish and calcareous nature of these lagoons The ephemeral Cape Naturaliste lagoons were acidic reflecting their dystrophic character. All lagoons displayed to varying degrees temporal variation in pH.

Most lagoons showed a steady rise in K_{25} with summer then a fall with the onset of winter. Most lagoons also showed a distinct drop in conductivity in January following high rainfall in December. This was then followed by variable but slow increase in K_{25} as the year progressed. Cape Naturaliste No. 1 displayed the greatest temporal range as expected (570-2100 μS cm^{-1}). Initially conductivity was low following high rainfall of the previous month, but became relatively quite high towards the end of March-early May. The largest of the lagoons, Big Waterhouse Lake, apart for an initially high value was relatively constant and displayed the least temporal variation(261-754 μS cm^{-1}). The initial high reading of 2190 μS cm^{-1} is considered an anomaly. To a somewhat lesser degree Little Waterhouse and Blackmans Lagoon followed Big Waterhouse Lake.

Na and Cl were the major ions in all of the lagoons The two Cape Naturaliste lagoons had a predominantly sea water ionic dominance of Na>Mg>Ca>K:Cl>SO_4>HCO_3. Cape Naturaliste No 1 showed anion temporal variation with Na>Mg>K>Ca on two occasions and the cations Cl>HCO_3>SO_4 on one occasion Both Big Waterhouse Lake and Bowlers Lagoon showed calcium bicarbonate enrichment with a predominant ionic order of Na>Ca>Mg>K:Cl>HCO_3>SO_4 Blackmans Lagoon displayed a sea water anion order of dominance but bicarbonate enriched cation order of Cl>HCO_3>SO_4 Little Waterhouse Lake showed variation in Ca and Mg with these two ions alternating in dominance and relative proportions. This lagoon had a similar cation order to the other permanent lagoons -i.e. Bowlers Lagoon, Blackmans Lagoon and Big Waterhouse Lake.

Chlorophyll a values for the lagoons indicate the low trophic status of these waterbodies and based on OECD (1982) values they would be classified as oligotrophic (chlorophyll a values <0-5 μg/l). Though Blackmans Lagoon and Bowlers would have on one occasion each have been classified as eutrophic with chlorophyll a values >10 μg/l. The ephemeral lagoons of Cape Naturaliste whilst predominantly oligotrophic showed a greater degree of temporal variation in chlorophyll a, displaying mesotrophy and eutrophy on occasion

The major nutrients (Total P, NO_2 and NO_3) were analysed for the NE lagoons and returned values indicative of waters of high to very high trophic status (**Appendix** 6). General criteria for nutrient concentrations and trophic status for Australian lakes for Total P (Wood 1975) showed that all of the lagoons displayed varying degrees of Meso-eutrophy (i.e. Total P = 0 1-0 3 mg/l).

Ordination of the environmental variables (**Figure** 5.3) measured (not including major nutrients) indicates the strong positive association of K_{25} and the ions Na, Mg, K and Cl with principal component 1 (PC1). These environmental variables had 78-95% of variance explained by

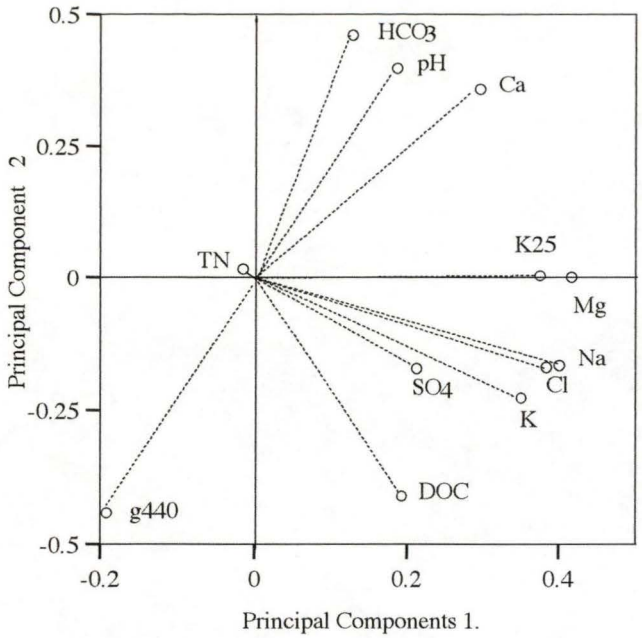


Figure 5.3 PCA of the Environmental Variables for the North East Lagoons studied intensively between Nov.1993-Oct.1994.

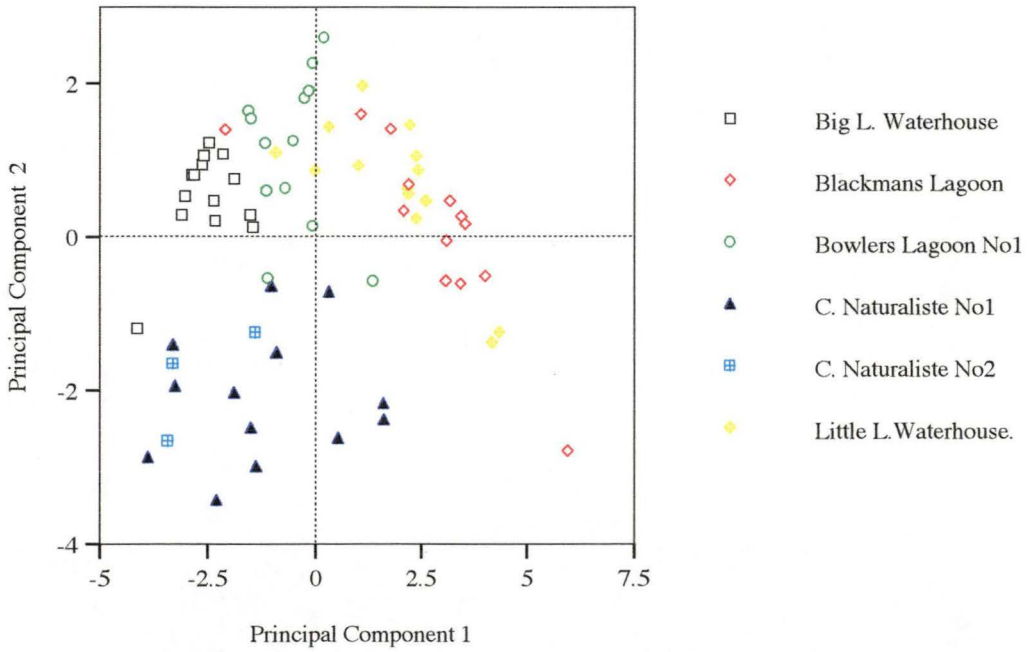


Figure 5.4 Component scores for the North East lagoons intensively studied between Nov.1993 - Oct.1994.

PC1, with the exception of K (68%). Ca was less strongly positively associated with PC1 (50%) and by principal component 2 (PC2) had 80% of variance explained In comparison HCO_3 and pH were positively associated, and, g_{440} and DOC were negatively correlated with PC2. PC2 accounted for 50%, 62%, 55%, and 56% of total variance for pH, g_{440}, HCO_3 and DOC respectively. Tn and SO_4 were more closely correlated to PC3.

PC1 and PC2 component scores for each variable, plotted as X-Y coordinates (**Figure** 5 4), showed that the two Cape Naturaliste lagoons separated from the other four lagoons forming a dispersed but distinct group. Blackmans Lagoon, Bowlers Lagoon and Little Waterhouse Lake formed another cluster. Big Waterhouse Lake formed a third cluster with a relatively tight grouping and little overlap with the other groups

5.7 DISCUSSION

The five lagoons in this study are surface expressions of a unconfined aquifer and receive inputs from the groundwater and runoff from surface catchments (Bowden 1978) Outflow from these wetlands occurs via the groundwater and water is lost directly from the wetlands with evaporation and evapotranspiration. The mediterranean-type climate, with hot, dry summers and cool, wet winters, in concert with the existence of the unconfined aquifer, profoundly shapes the character of these wetlands. The seasons are quite distinct in terms of temperature and rainfall (Bowden 1978). There is a long decline in water quality through summer and autumn, an abrupt transition from drought to winter wet and cold, a relatively short improvement in environmental quality culminating in spring and a gradual change from spring to summer. The annual sequence of seasonal change is predictable, only the length of the wet and dry seasons varies In this the NE lagoons are similar to those of the Swan Coastal Plain (Balla & Davis 1993).

5.7.1 Seasonal-monthly sampling

The sampling period of these lagoons coincided with one of the driest years on record for the North East of Tasmania This unseasonably dry year was evident in both number of monthly rainfall (**Figure** 5.5) and raindays (**Figure** 5.6) for the calendar year 1994 All three meteorological stations, Rushy lagoon, Gladstone and Bridport recorded the lowest annual totals on record (490.6 mm, 528.1 mm and 386.6 mm respectively). Comparison of data from previous years shows that rainfall was down to a half of that regions yearly rainfall. The lack of rainfall had significant implications for the physicochemical character of the lagoons when compared to the more "normal" rainfall cycle of the region (Chapter 3). During the reconnaissance of the lagoons 1992-1993, rainfall was more typical and as a consequence water levels usually reach a peak by spring, then progressively decrease until winter when substantial rains commence -i.e when some 80% of the years rainfall occurs. There is a distinct summer "Dry" and a winter "Wet" (Chapter 3). However during this period of monthly sampling of the lagoons, there was little winter rain. Water levels in the lagoons fell as summer (1993-94) progressed, there was a slight rise in levels with the onset of winter, then a pronounced decline with the onset of the following summer (1994-95). The expected result was a marked increase in depth of the lagoons with the onset of the expected winter rains during July-September. The relatively dry winter ensured this did not occur so already low water levels in the lagoons were lowered further during the following summer of 1994-95. The slight rise in water levels observed during the later part of the year may in part be attributed to

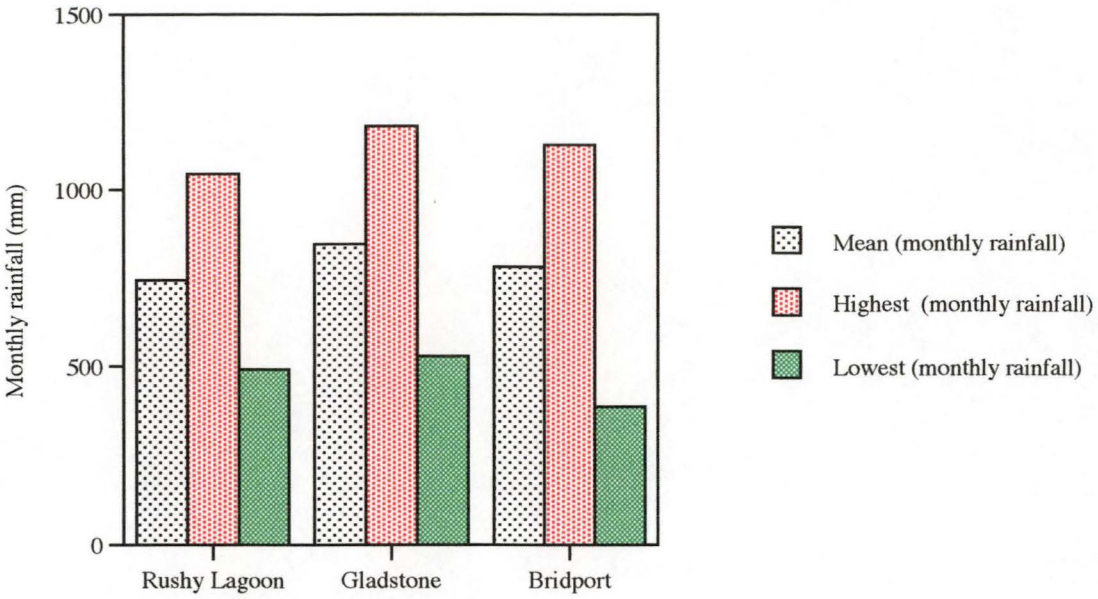


Figure 5.5 Summary of Monthly Rainfall using all available data between 1965 and 1995. Bureau of Meteorology.

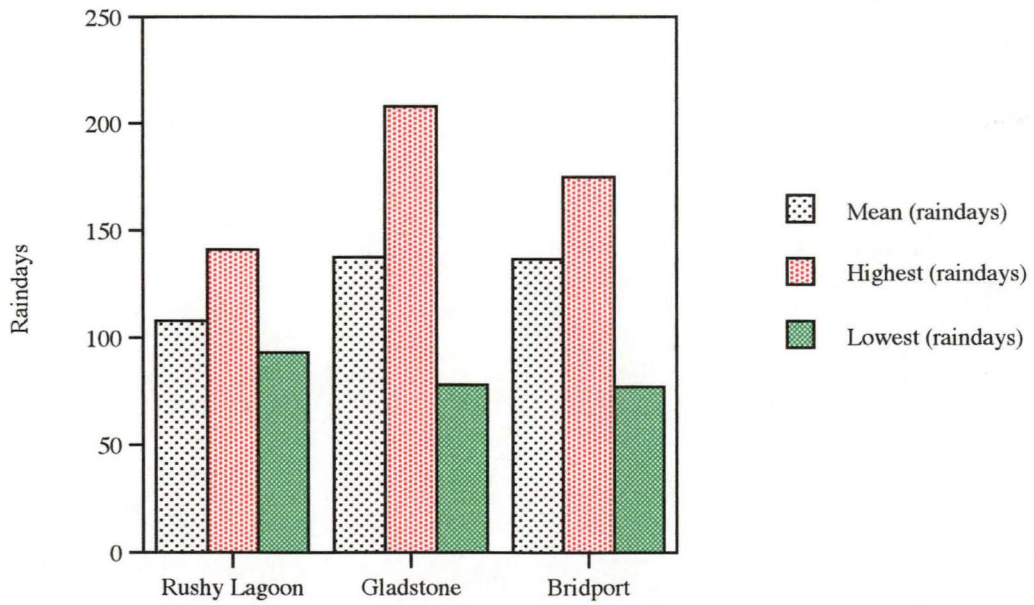


Figure 5.6 Summary of number of Raindays using all available data between 1965 and 1995. Bureau of Meteorology

recharge from groundwater.

The magnitude of water level fluctuations is influenced by hydraulic parameters which vary from site to site. In years of high rainfall many of the ephemeral wetlands of Cape Naturaliste would not dry at all. In years of average or below average rainfall the length of the dry phase can vary from only a few weeks to several months For example Cape Naturaliste No 1, except for a small pool several centimetres deep, was dry on a number of occasions. The timing of refill of seasonal dune lakes appears to be directly in response to rainfall, because the dry phase ceases when a large volume of rain fell and refill occurred rapidly. A rise in water levels of 2 2-2.8 cm/day is not uncommon in lagoons of the Swan Estuary (Davis *et al.* 1993) Cape Naturaliste was observed to rise 2 cm in 4 hours following intermittent showers during the 24 hour sampling period 9/3/94. The timing of drying is affected by the previous years rainfall, and the previous years maximum and minimum water levels. In years of below average rainfall the groundwater levels are lower and therefore, drying of the seasonal wetlands occurs earlier. The timing of drying is primarily a response to the volume of rainfall, while the timing of refill is primarily a response to the timing of rainfall (Davis *et al.* 1993).

The below-average rainfall influenced both conductivity and solute concentrations of the lagoons. As expected the greatest influence was on the ephemeral lagoons Those lagoons which are very shallow and have a relatively large surface area -eg Cape Naturaliste No 1, tend to evaporate rapidly in summer, reaching high solute concentrations. The years data for Cape Naturaliste No. 1 showed the greatest temporal variation Bowlers Lagoon recorded relatively high conductivity that coincided with high turbidity This high turbidity was the result of livestock, observed wading in the shallows and this encouraged the release from sediments of mineral salts into the water column. Conductivity in all of the lagoons showed an increasing trend in the later half of the year as water levels fell due to below average rainfall and onset of summer.

All of the lagoons have Na and Cl as the dominant ions with Cl>Na reflecting the proximity of these lagoons to the coast. The dominance of Na and Cl indicates the relative ionic proportions are determined by the precipitation of airborne sea spray. Secondary cations are dominated by Mg or Ca. The relative dominance of Mg and Ca is determined by the landform in which the lagoon occurs. Those lagoons with Ca>Mg are associated with sands of high calcareous content i e. shell fragments and grit. The majority of the lagoons have high bicarbonate levels and this is reflected in the alkalinity of those lagoons

The majority of lagoons have, by Australian standards, relatively low turbidities, probably because there is little inflow of surface water. Large external sediment loads would not be expected for most of the lagoons, however, because they are found mostly in non-eroding landscapes. The shallower lakes also tend to be more turbid because wind-mixing disturbs the bottom sediments. Turbidity in all lagoons was relatively high on 1/9/94. This is probably due to low water levels and windy conditions that are prevalent during this period of the year. Bowlers Lagoon No 1 experienced the the highest turbidity of the five lagoons sampled through out the year. On the 4/5/94 a value of 10.00 NTU was recorded. This is attributed in part to windy conditions on the day of sampling, but also due to cattle moving through the lagoon shallows. Cape Naturaliste No. 1 experienced the greatest temporal range in turbidity, reflecting the shallowness of this lagoon, proximity to coast and exposure to prevailing winds with resuspension of sediments. This lagoon is very shallow and has very peaty sediments, so that fine particles are continuously being resuspended

by mixing of the water column. In comparison Blackmans Lagoon experienced the smallest seasonal range in turbidity. As water levels in the lagoons fell with progression of summer, coupled with the unseasonably low rainfall, turbidity of the lagoons would have expected to be more variable and also higher The low water levels would have decreased the amount of work required to mix the water column and disturb the sediments. Therefore, even at lower wind speeds, turbidity would have been higher.

Levels of g_{440} varied between the lagoons, and consist mainly of coloured compounds derived from the breakdown products from plant material and phytoplankton, largely humic and fulvic acids. These can be formed within the wetlands or transported via surface or groundwater, and their concentrations are affected by local vegetation types, soil mineralogy and agricultural practices g_{440} generally tended to be highest in spring and summer and lowest in winter, probably due largely to the effects of evapoconcentration and dilution, as well as the increased production and release of coloured compounds during the periods of maximum plant growth. External inputs of g_{440} would also peak in late winter and spring as groundwater and surface water inflows peak

pH varied not only between lagoons but also within lagoons Seasonally Big Waterhouse Lake, Little Waterhouse Lake and Blackmans Lagoon were relatively constant. The value of pH 4.0 recorded for Big Waterhouse is an anomaly and is considered to be a contaminated sample. Cape Naturaliste No. 1 was typically acidic with pH predominantly <7 However the below average winter rainfall and shallowness of this lagoon saw a rise in pH as water level declined In comparison the permanent lagoons showed too much temporal variation to comment:

Nitrogen in water comes in several different forms; as dissolved N_2 gas, as organic compounds and as the inorganic forms NH_3, NO_2 and NO_3. All lagoons had levels of nitrate and nitrite below detectable limits. This may have been an artifact of methodology used and also due to the delay in time of sampling until analysis. Even though samples were stored in ice and dark following sampling, and presented to the Government Analyst immediately upon return from the field, sufficient time may have elapsed for levels of nitrate and nitrite to fall below detectable limits Another explanation is that levels were low as available N had been utilised and the lagoons were N limited. No estimates of dissolved N_2 or organic compounds were made NO_3, NO_2 and NH_4 are inter-convertible through the processes of nitrification and denitrification. NH_4 is largely derived from the mineralisation of organic nitrogen compounds by microbial activity. This is then taken up by macrophytes and algae, or converted to NO_2 and then NO_3 by nitrifying bacteria under aerobic conditions Nitrification, the conversion of NH_4 to NO_3 is also inhibited by high levels of coloured compounds and low pH. This may also explain in part the low levels of NO_2 and NO_3 in the more dystrophic samples and particularly for Cape Naturaliste. NO_3 is usually the dominant form of inorganic nitrogen in wetlands (Davis *et al.* 1993). All of the five lagoons studied showed peaks in of NO_3 in May 1994 and this is associated with a flush of NO_3 as ground water and surface water inflows increase following increased rainfall.

Phosphorus is often the nutrient limiting primary production Sources of P to a lagoon are surface water , ground water, rainfall and dry atmospheric precipitation. Losses are primarily due to sedimentation and ground water flow (Davis *et al.* 1993). The exceptions to this are Big Waterhouse Lake and Blackmans Lagoon which have artificial inflowing drains and these may have altered the dynamics of P budgets to these two lagoons. Lagoons of the North East Coastal Plain are poorly flushed in that they posses long water residence times Therefore nutrients that enter the

lagoon will tend to accumulate and eventually be incorporated in the sediments Thus, a large reservoir of nutrients is held in the sediments and under certain conditions may be released and recycled to the water column The exchange of P between the sediments and water is largely dependant upon pH and oxidative conditions. These are in turn controlled by microbial activity in the sediment surface layers In oxygenated conditions microbes use oxygen as an electron donor in oxidising organic material. If oxygen is consumed in the sediment faster than it is replaced by diffusion, the water immediately above the sediments becomes anoxic. **Table** 5.2 shows the reduction reactions and approximate O_2 levels at which they begin to be reduced in the sediment (Bostrom *et al.* 1982)

Table 5.2 reduction reactions & critical O_2 concentrations.

Reduction Reaction	Oxygen concentration (mg/l)
NO_3 - NO_2	4.0
NO_2 - NH_3	0.4
Fe^3 - Fe^2	0 1
SO_4 -S^2	0.0

In deoxygenated waters Fe^3 is reduced to Fe^2 and any P bound to it is released. This is thought to be the major source of P release from sediments. High levels of NO_3 in the water will inhibit P release as NO_3 will be preferentially reduced before Fe^3.

Two of the wetlands had bottom water levels of O_2 less than 4.0 mg/l. Bowlers Lagoon consistently had bottom waters with low levels of O_2 and once had anoxic conditions. Cape Naturaliste No. 1 also had an O_2 bottom water level of less than 4.0 mg/l on one occasion. No specific attempt was made to collect data on deoxygenation. Levels may well have been lower in these lagoons and frequently so Nevertheless, data that was obtained suggests that substantial P release from sediments, of the well vegetated lagoons such as Bowlers Lagoon, may occur due to deoxygenation of bottom waters Bowlers Lagoon had the highest levels of P of any lagoon when its bottom waters were anoxic or almost so.

Table 5 3 Trophic status of a lake based on Chlorophyll a (OECD 1982)

Trophic Status	Chlorophyll a (µg/l
Oligotrophic	0-4
Mesotrophic	4-10
Eutrophic	10-100

The trophic status of the lagoons varied depending not only on which classification scheme used, but also seasonally The definitive classification of trophic status of lakes is that of the OECD (1982) (**Table** 5.3) There are problems in applying this criterion globally, as this scheme is based largely on data from Northern Hemisphere alpine glacial lakes at high latitudes. Values

increase little past 100 μg/l irrespective of nutrient loading due to self shading, and these boundaries are not fixed rigidly. Salias and Martinos (1991) developed a classification scheme to assess the trophic status for tropical warm-water lakes. This scheme has been applied to the lakes, lagoons and wetlands of the Swan Coastal Plain with some success (Davis *et al.* 1993) Wood (1975) developed a scheme based on nutrient concentrations for Australian lakes (**Table** 5.4) The trophic status of the lagoons varied depending on which classification scheme used

Table 5.4 Nutrient concentration (in μg/l) and trophic status in Australian lakes (Wood 1975)

Trophic status	Total P	Inorganic N.
Ultra -oligotrophic	<5	<200
Oligo-mesotrophic	5-10	200-400
Meso-eutrophic	10-30	300-650
Eu-polytrophic	30-100	500-1500
Polytrophic	>100	>1500

Individual lagoons fitted different categories depending on which scheme was used. Using the OECD (1982) criteria then all lagoons were oligotrophic with Blackmans and Bowlers Lagoons both eutrophic once on separate occasions. In contrast, using Wood (1975), then all lagoons were mesotrophic-eutrophic with Bowlers Lagoon polytrophic on three occasions.

The very high levels of P relative to Australian mainland lakes is attributed to natural eutrophication. The North East lagoons are relatively shallow, with fluctuating shorelines and during late summer large areas of sediment are exposed. As a consequence nutrients are highly evapo-concentrated and remain in the lagoon due to lack of outflow. The lagoons also have a low capacity to assimilate nutrients due to their relatively small size and depth.

Vollenwieder (1968) established close correlation between Chlorophyll a and P concentrations. Since then there has been a very large number of models relating P loading to Chlorophyll a concentrations based on a number of different data sets (Dillon *et al.* 1988). There are significant differences between models based on the different data sets. Therefore accuracy of chlorophyll a predictions varies and is often low. This is due to use of different analytical techniques for Chlorophyll a and P, use of different parameters, variation in chlorophyll content of different algal species, physiological state of the algae, differing physicochemical environments, nutrient availability, sedimentation rate, and water residence time (Davis et al. 1993).

5.7.2 Diurnal Sampling

Diurnal studies of the physicochemical processes of standing bodies of water have concentrated upon large deep water lakes, reservoirs and impoundments. There have been few on shallow or ephemeral water bodies The range in seasonal water temperatures is significantly different both spatially and diurnally. Thin sheet ice was observed on a number of lagoons in the littoral margins

The shallowness of Cape Naturaliste Lagoon No. 1 accentuates rapid heating during the daylight hours and cooling by night (**Figure** 5.7). The approximate times of dusk and dawn are

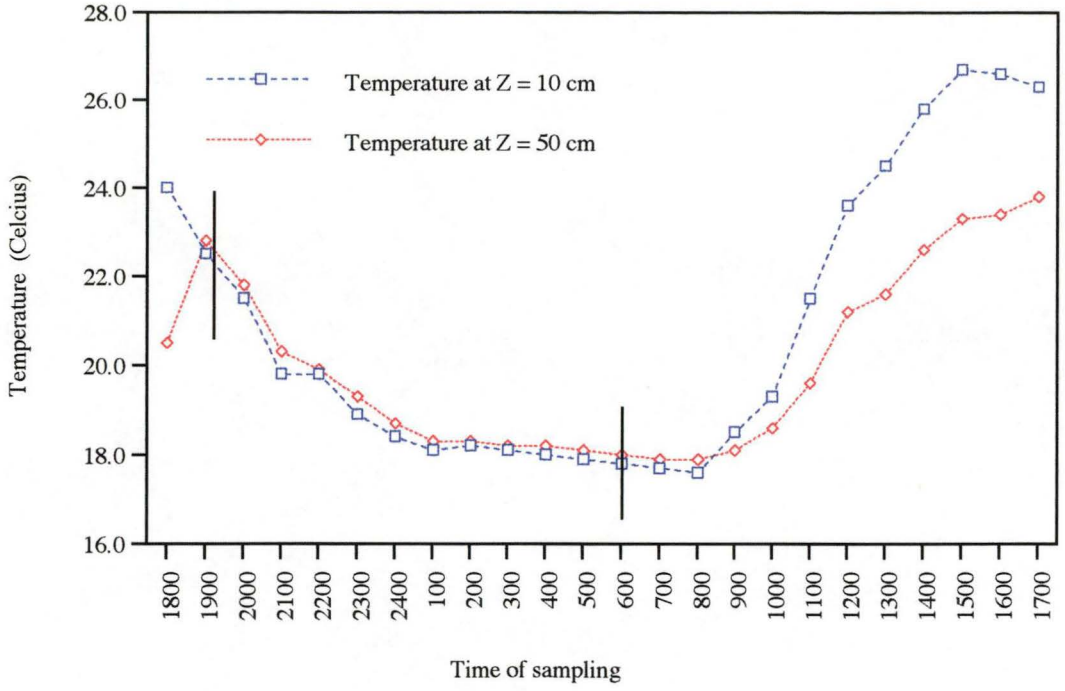


Figure 5.7 Cape Naturaliste No.1 Temperarure 24 hr Series 9/3/94

NB: Vertical bars indicate approximate position of Dusk and Dawn

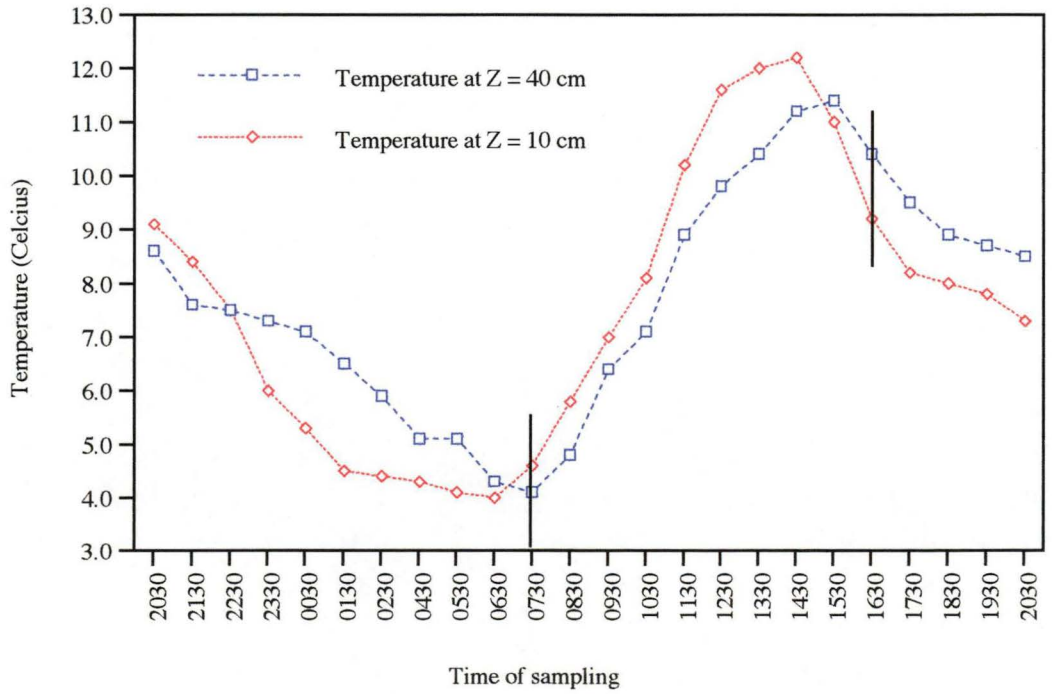


Figure 5.8 Cape Naturaliste No. 1 Temperature 24 hr Series 27/7/94

NB: Vertical bars indicate approximate position of Dusk and Dawn

shown. Water temperatures in summer are twice that experienced in winter (**Figure** 5.8). Comparison of the two dates 8-9/3/94 and 26-27/7/94 highlight the temporal difference in water temperatures for Cape Naturaliste No. 1 Late summer water temperatures are high with a diurnal range between 17.9-23 8° C in 50 cm of water and 17.6-26 7° C in 10 cm of water. The spatial difference in water temperature in summer (8-9/3/94) is noticeable with the greatest difference at dusk of 3.5° C between the shallows and deeper water During the night temperatures fall to approximately the same level around 18° C In winter there is more rapid loss of heat and warming of the shallows (Figure 5.8) with temperatures in the shallows (10 cm) 4.0-12.2° C and 4.1-11.4° C at 50 cm. The difference in depth being only 40 cm highlight the possibility of thermal stratification on calm, windless days.

The limited nutrient data set for the 24 hour sampling series of 26-27/7/94 is in general agreement with that known elsewhere for shallow wetlands. The spike in NO_2 and NO_3 (**Figure** 5.9) may be explained by daylight nitrification, i.e. the conversion of ammonia NH_3 to NO_2 and NO_3. Nitrification occurs only in an oxic environment. Photosynthetic release of O_2 into the water column stimulates the nitrification process (Risgaard *et al.* 1994). This retards the reverse of nitrification which is the process of Dissimilarity Nitrate Reduction, -i.e. the conversion of NO_3 to NH_3.

The fall in ammonia (NH_3) occurs with a simultaneous rise in NO_2 and NO_3. This is consistent with an increase in nitrification during daylight hours The rates of nitrification and denitrification are controlled by the availability of substrates. Therefore as NO_2 and NO_3 levels peak (at approximately 10.00 am) following when all available NH_3 is consumed (ie at 9 00 am), the nitrification process is retarded, and NH_3 levels then rise until both processes stabilize -i e. there is a steady state between nitrification and denitrification in the later hours of the day from 5 pm onwards (**Figure** 5.9).

However the data for PO_4 argues against the above conclusion as PO_4 is released from the sediments under reducing conditions. The peak of PO_4 during 10-11.00 am may be be due to algal utilization with an increase in available light and in water temperature (**Figure** 5.9).

Chlorophyll a shows a peak during early afternoon centred around 2.00 pm. The peak in chlorophyll a follows a rise in pH, peaking at 12.30 pm The rise in pH, as expected, is consistent with a rise in photosynthesis during midday when temperatures are warmest and photosynthetic available radiation is highest (**Figure** 5.9).

DO_2 was relatively constant throughout the sampling period and changed little This may be attributed to Cape Naturaliste being a very shallow lagoon, with diffusion of O_2 from the atmosphere and mixing by wind, ensuring the water column is well oxygenated. The shallowness of the lagoon (<0.5 m) and lack of macrophytes ensuring little chance of deoxygenation.

Temperature measurements taken over the same period showed a more rapid heating and cooling of the littoral shallows (10 cm depth) compared to the centre of the lagoon (0.5 m depth).

5.8 CONCLUSION

The five wetlands are a subset of the wetland types on the North East Coastal Plain. They are fresh to slightly saline lakes with areas of open water. They range in size from small (2 ha) to large (126 ha). Cape Naturaliste No. 1, except for a small pool dried completely, while Little Waterhouse Lake, Bowlers Lagoon, Blackmans Lagoon and Big Waterhouse Lake, contained water over most of

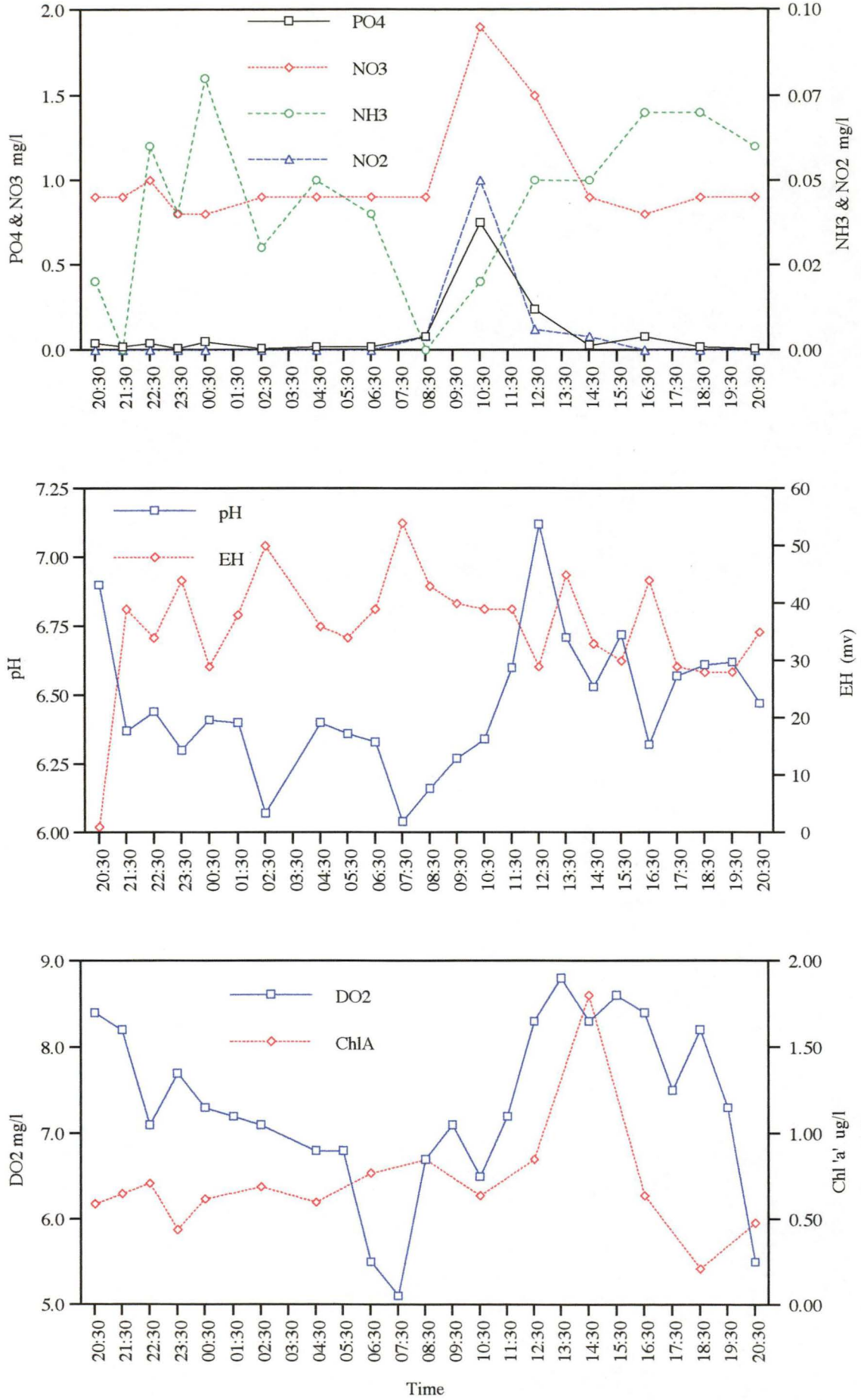


Figure 5.9. Cape Naturaliste 24 Hour series 27/7/94 - Major Nutrients, pH, EH, DO2, Chl 'a'

their surface area all year.

The wetlands encompass a range of depths, pH, conductivities, nutrient levels and colour. Big Waterhouse Lake had the lowest chlorophyll and nutrient levels (classified as mesotrophic), while Bowlers Lagoon was moderately enriched (eutrophic) on several occassions. Cape Naturaliste No 1 did not exhibit symptoms of enrichment, probably because of the dark colour of the water, and is more properly classified as dystrophic. Depending on criteria used the trophic status of the lagoons varied.

The range of temperature for each lagoon varied diurnally and seasonally The range of temperature on a daily basis is dependant upon season and lagoon depth. Seasonal changes in conductivity and ionic proportions as a result of evaporative concentration were noted in all lagoons, but are more pronounced in the shallow ephemeral lagoons of Cape Naturaliste. Whilst thermal stratification was not observed, comparison of temperatures between littoral shallows and deeper waters within respective lagoons indicate that transient thermal stratification may occur in some lagoons on warm still summer days or very cold, still mid winter nights. The limnological character of each lagoon was dependent upon the hydrological cycle as affected by the strongly seasonal climate experienced in the North East The annual sequence of seasonal change is predictable; only the length of the wet and dry seasons varies. In this the NE lagoons are similar to those from the Swan Coastal Plain

Each lagoon is a dynamic system that may vary in many ways from even its nearest neighbour. Each lagoon is distinguished by a combination of features, including landform, morphometry and chemical composition of its waters which are a result of short and long term environmental changes. The seasonality of the lagoons has important ecological implications for the invertebrate faunas of these waterbodies.

CHAPTER 6
MICROCRUSTACEAN ECOLOGY IN 5 NORTH EAST LAGOONS.

6.1 ABSTRACT

Microcrustacean community composition and population abundance showed temporal variations in each lagoon. The degree of change varied between each lagoon as community composition and different populations responded to differing degrees of natural disturbance Microcrustacean species diversity was highest in seasonal lagoons; or in permanent lagoons with fluctuating shorelines, possessing extensive, dense and complex aquatic macrophyte communities. The macrophyte communities provided diverse spatial habitat heterogeneity. Ecologically the lagoons represent an environmental mosaic of aquatic habitats in NE Tasmania. Each lagoon is in a constant state of flux and is a dynamic system in time and space discrete from its nearest neighbour.

6 2 INTRODUCTION

The microcrustacean species occurring within the coastal dune lakes of the North East Coastal plain form a very rich assemblage in comparison with those of other areas of Australia. This is attributed to the marked seasonal variation in the aquatic environment of this region, which is brought about by the winter rainfall maximum. The expansion of the aquatic environment in the 'Wet season', with the associated proliferation of aquatic macrophytes, creates a wide range of physical habitats for littoral microcrustaceans

As water levels fall with the progression of the summer 'Dry season', weedbeds decline and lagoons and other waterbodies contract or dry out on the coastal plains. Littoral species assemblages decline because of the lack of suitable habitats, and open water species assemblages reform after cessation of the high water flow rates of the Wet season. A reduction in species diversity was evident towards the end of the Dry season, particularly in smaller water bodies, where deterioration in water quality was more marked as they dried

In view of the importance of coastal dune lakes to the aquatic system, further investigation of both limnetic and littoral microcrustaceans is required to provide more detailed information of seasonal population dynamics and statistically verifiable population density estimates. Investigation of differences in the littoral microcrustacean species assemblages between weedbeds of different macrophyte species would also provide an overall view of littoral microcrustacean populations in coastal dune lakes.

Deficiencies in the sampling program among aquatic macrophytes (Chapter 4), i.e. the lack of short interval (weekly, fortnightly or at least monthly) sampling, limited analysis of littoral microcrustacean population dynamics. It is likely that the number of species obtained is an under representation of the true number present in the wetlands As sampling was carried out at approximately three monthly intervals, a more intensive sampling program would be more desirable, particularly amongst the macrophyte beds. With more frequent sampling (i.e. shorter intervals between sampling) of both the littoral and limnetic zones and use of different sampling methods, a greater number of microcrustacean species will be identified from individual water bodies and the wetlands as a whole. Also a more true picture of species seasonality, species assemblages and dynamics would emerge.

6.3 AIMS

The aims of this part of the study were threefold:

a) To investigate seasonal change in the microfaunal community of permanent, and

ephemeral coastal lagoon ecosystems,

b) To compare the degree of change in the microfaunal community within and between seasonally ephemeral and permanent lagoons respectively.

c) To increase knowledge of the ecology and life histories of microcrustacea.

Particular attention was focused on the role of the hydrological regime of permanent and seasonally ephemeral lagoons.

6.4 STUDY SITES

Investigation of six lagoons occurred on a monthly basis during the 1993-1994 survey. The study sites Cape Naturaliste No. 1, Bowlers Lagoon No. 1, Big Waterhouse Lake, Little Waterhouse Lake, and Blackmans Lagoon have been described in detail in Chapter 3. One site, Cape Naturaliste No. 2 was abandoned early in the study due to problems with access. The Cape Naturaliste lagoons are ephemeral in nature, with indefinite shorelines, fluctuating water levels and variable physicochemical characteristics. In contrast the other lagoons are permanent lagoons displaying relatively little seasonal amplitude in their hydrological and physicochemical regimes. All the sites are shallow coastal lagoons, of varying dystrophy, close to sea level and occupying deflation hollows located in siliceous or calcareous dunes The study sites differ physiognomically, ranging from large relatively exposed lakes to small ephemeral ponds, with depths of <0 5 m to 4.0 m, from open water bodies to those dominated and covered by emergent macrophytes.

6.5 METHODOLOGY

6.5.1 Collecting:

Biological and physicochemical samples (Chapter 5) were collected every four to five weeks, between November 1993 and October 1994 from five lagoons between Cape Naturaliste and the township of Bridport. This frequency of collection was mainly to provide an indication of the variation among the lagoons, largely covering a range of wetlands types over the study area. This intensive sampling regime was required for a greater understanding of the dynamic processes occurring in a particular lagoon.

Zooplankton samples were collected by one or more oblique tows with 20 μm and 200 μm conical nets in deeper lagoons, and by hand held 20 μm and 200 μm conical nets in the more shallow Cape Naturaliste lagoons. All collections were preserved in 5-10% formalin, pending identification. Nets were washed thoroughly before and after the sampling of each site in an effort to reduce the possibility of contaminants in the samples obtained.

Identification of the cladocera and copepods, and disarticulation methodology when required is discussed in greater detail in Chapter 2.

6.5.2 Data Analysis

Community data was recorded as either presence or absence of species for each of the respective lagoons. On each sampling date, the results from each of the three sampling techniques (20 μm and 200 μm conical nets and quantitative samples), were pooled for each site. The taxa from the pooled data set, using all sampling dates for each lagoon, were analysed to determine if there was any seasonal difference in species richness between the five lagoons.

The statistical package PRIMER was used to sort the respective sites by date, based on their community data, into similar classes. PRIMER uses the Bray-Curtis similarity co-efficient to group sites, based on community presence/absence data, into classes so that similar ones are in the same class. This analysis was done firstly to define "true" groups and secondly for data reduction. The inter-relationships between sites and sampling date where then mapped in an ordination by non-metric multi-dimensional scaling (MDS), to visualize community patterns.

The null hypothesis (Ho), that there was no difference in community composition between permanent and ephemeral sites, was tested by one-way Analysis Of Similarity (ANOSIM) ANOSIM is used to test the site to site differences in community structure before going on to interpret these differences in terms of their biology or environmental conditions.

The PRIMER program SIMPER was used to analyse the pooled temporal community data for identification of key species in each of the lagoons SIMPER calculates the Bray-Curtis dissimilarity between all pairs of inter-group samples (i.e. every species in group one paired with every species in group two). The Bray-Curtis dissimilarity is first averaged over all pairs and then broken down into the separate contribution from each species to the overall dissimilarity between the two groups. Indicator species were identified as those species which contributed the greatest percentage of dissimilarity to separate faunal assemblages of the five lagoons.

6.6 RESULTS

6.6.1 Species Diversity

A total of 8 calanoid species and 27 cladoceran taxa were recorded from all lagoons over the course of the study. In addition 2 amphipod species, six ostracod species and three harpacticoid species were identified. A number of unidentified cyclopoid species were also collected (**Appendix** 7-11).

The most diverse group was the chydorids with 18 different taxa recorded. This is thought to be an under representation as several taxa were not identified below genera and are known to include a large number of species (- e.g. *Alona*, *Alonella*, *Biapertura*) This was due to poor taxonomic resolution of these groups in Australia

The lagoon with the most diverse microcrustacean fauna was Cape Naturaliste No. 1 (**Appendix** 7) followed by Little Waterhouse Lake (**Appendix** 8), with 37 and 34 microcrustacean taxa respectively. The least diverse lagoon was Bowlers Lagoon (**Appendix** 11) with 22 taxa. Interestingly Bowlers Lagoon had only chydorids, daphniids and harpacticoids. It also had the most number of chydorid taxa (shared with Little Waterhouse Lake). Cape Naturaliste No. 1 was the most diverse in calanoids, macrothricids and was equal with Little Waterhouse Lake in ostracod diversity. Cape Naturaliste No. 1 was the only lagoon with *Ilyocryptus* that was analysed quantitatively.

6.6.2 Statistical Analysis

Temporal community data were analysed using PRIMER Bray-Curtis Similarity Coefficient (see Chapter 2) for each of the five lagoons. Analysis of the seasonal community data indicated that there was greater temporal similarity within a site than between the five sites (**Figure** 6.1). The sample dates for each lagoon clustered into distinct groups identifiable with each lagoon.

Three outliers were readily apparent and separated early at 15-20%. Bowlers Lagoon No. 1 (6/4/94) and (12/10/94), and Big Waterhouse Lake (12/10/94). All three were separated due to

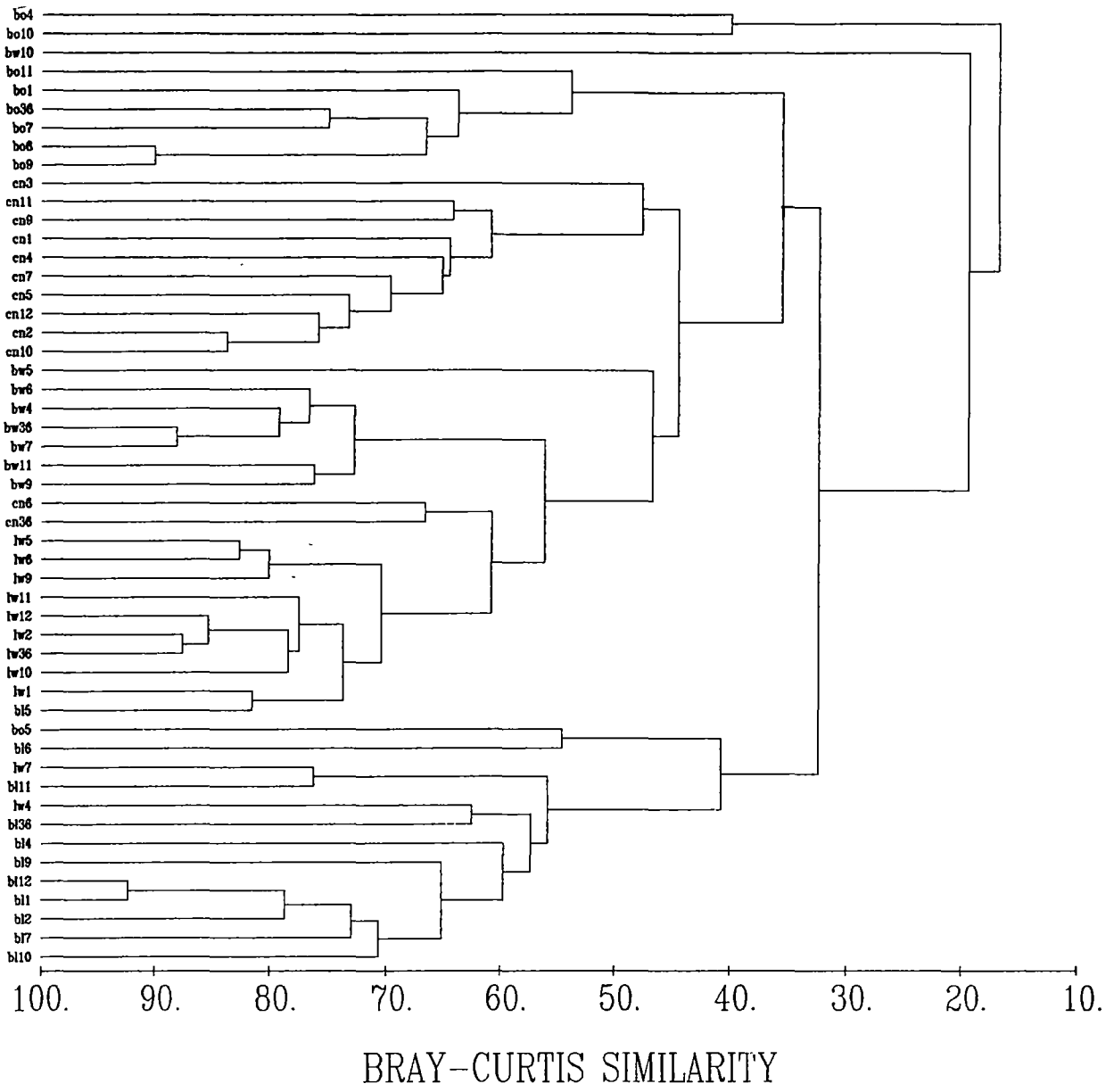


Figure 6.1 Dendrogram resulting from cluster analysis of NE Tasmanian dune lakes, based on community composition, sampled 1993-1994. (AA/12 = Site / month of sample).

CN = Cape Naturaliste

BL = Blackmans Lagoon

LW = Little Waterhouse Lake

BW = Big Waterhouse Lake

BO = Bowlers Lagoon

depauperate species diversity rather than similarity in their respective assemblages.

Little Waterhouse Lake (6/4/94) and (28/7/94) were included with Blackmans Lagoon Comparison of fauna showed that for (6/4/94) Little Waterhouse Lake had few chydorids and none on (28/7/94). Blackmans Lagoon, in comparison to the other sites, had a depauperate chydorid fauna for much of the sampling period. These two sampling dates for Little Waterhouse Lake were thus included with those of Blackmans Lagoon due to lack of chydorids and similarity in other cladoceran taxa present. In contrast Blackmans Lagoon (5/5/94) faunal assemblage showed similarity to that of Little Waterhouse Lake (9/1/94) and was clustered with that lagoons grouping.

Similarly, Bowlers Lagoon No. 1 (5/5/94) had few taxa and those which it did were similar to the faunal assemblage of Blackmans Lagoon (2/6/94). The sampling dates (2/6/94 and 30/6/94) for Cape Naturaliste No. 1 were more similar in faunal composition to Little Waterhouse Lake than to other sampling dates for Cape Naturaliste This is attributed to the absence of *Ilyocryptus* sp. on these dates and similarity in the other cladoceran fauna present. Interestingly *Ilyocryptus* sp. was also absent in Cape Naturaliste No. 1 on 9/3/94. This date was separated from the rest of the sampling dates for that site, but was still sufficiently similar as not to group it with another lagoon.

In short, based on the Bray-Curtis Similarity Coefficient, Blackmans Lagoon was the least in similarity to the other four lagoons, closely followed by Bowlers Lagoon No. 1 at 33% and 35 % respectively The next lagoon to be separated was Cape Naturaliste No. 1 at 45% level The lagoons most similar to each other were Little and Big Waterhouse Lakes and were not separated from each other until the 60% level.

MDS ordination of the community data for the five lagoons sampled over the period 93-94, showed that the individual sampling dates for each lagoon tended to group together with some overlap (**Figure** 6.2). All ordination methods are a compromise with dimensional data being displayed often in two dimensional planes. Therefore, the simplest indicator to assess how well it succeeds in any particular case is the stress value, where r = stress (Kruskal & Wish 1978). A low stress value indicates a valid configuration has been found Clarke's (1993) rule of thumb for interpreting the stress value in MDS is that stress (r = <0.05) corresponds to an excellent representation with little prospect of drawing false inferences. Nevertheless, in this case the value r = 0 17 still provides a usable picture (Clarke 1993)

Visually the different sites from the overall sampling pattern appeared to have differing community composition (i.e. clusters) based on the variation within the sites. The MDS plot largely agrees with the dendrogram clustering of community data. Little and Big Waterhouse Lakes appear to be the most similar with overlapping and relatively tighter clusters. Bowlers Lagoon appeared to be the most dissimilar to the other sites with a somewhat dispersed but separate cluster. Cape Naturaliste No. 1 formed a relatively tight group and differed from Blackmans and Bowlers Lagoons but with small overlap with Little and Big Waterhouse Lakes. Blackmans Lagoon had some overlap with Big and Little Waterhouse Lakes but distinct from both Bowlers Lagoon and Cape Naturaliste No. 1.

The degree of dissimilarity between the five lagoons was determined (**Appendix** 12). The SIMPER Bray-Curtis Dissimilarity coefficient (**Table** 6.2) showed the vegetated permanent lagoons of Blackmans Lagoon, Big and Little Waterhouse Lake were the most similar to each other in community composition. Bowlers Lagoon was the most dissimilar lagoon to all the other lagoons.

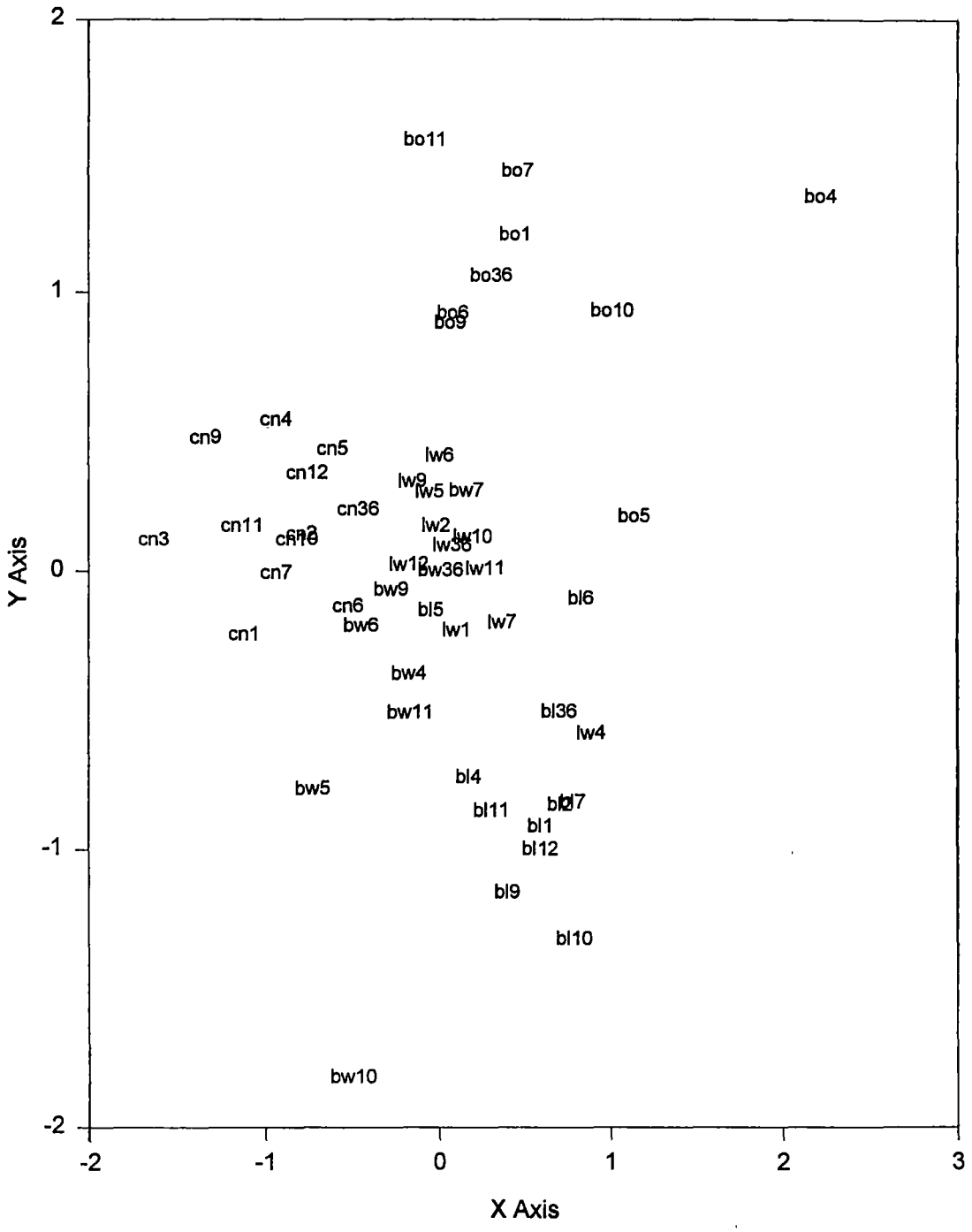


Figure 6.2 MDS ordination of NE Tasmanian dune lakes based on community composition, sampled 1993-1994. Stress level = 0.17.
(AA/12 = Site / month of sample).
CN = Cape Naturaliste, BL = Blackmans Lagoon, LW = Little Waterhouse Lake, BW = Big Waterhouse Lake, TR = Tregaron Lagoon, BO = Bowlers Lagoon.

Cape Naturaliste was very different to Bowlers and Blackmans Lagoons but more similar to Little Waterhouse in community composition than to Big Waterhouse Lake.

Table 6.2. Bray-Curtiss Average Dissimilarity between the community composition of the five lagoons Nov 93 - Oct 94

	BO	CN	LW	BW	BL
BO		76.92%	62.34%	71 67%	80.99%
CN	-	-	53.88%	62.45%	73.2%
LW	-	-	-	51.81%	52.28%
BW				-	63.45%
BL			-	-	

BO = Bowlers Lagoon, CN = Cape Naturaliste No. 1, LW = Little Waterhouse Lake, BW = Big Waterhouse Lake, BL = Blackmans Lagoon.

The null hypothesis (Ho), that there is no difference in community composition between sites was tested by One-Way ANOSIM. The null hypothesis was rejected (**Table** 6.3), suggesting that there was a significant difference between all the lagoons in faunal composition, at the significance level p = 0.05 (r = 0.675).

Table 6.3. Significance levels (p) from Pairwise Tests between lagoons community composition

	BO	CN	LW	BW	BL
BO		0 000	0.000	0.000	0.000
CN	-	-	0.000	0.000	0.000
LW	-	-	-	0.000	0.0001
BW				-	0.000
BL			-	-	

BO = Bowlers Lagoon, CN = Cape Naturaliste No 1, LW = Little Waterhouse Lake, BW = Big Waterhouse Lake, BL = Blackmans Lagoon.
NB: The significance levels in the pairwise tests ARE adjusted to allow for multiple comparisons. The null hypothesis was rejected at p = 0 05.

6.6.3 Quantitative Analysis

A total of 29,527 individual animals were sorted, counted and identified for three of the five lagoons sampled quantitatively (Cape Naturaliste No. 1 = 3,333; Blackmans Lagoon = 5,337; and Little Waterhouse Lake = 20,857). Totals for each taxa, on each sampling occasion were then divided by the volume of water sampled (in litres) to give no./l. Constraints in time precluded completing the other two lagoons. The littoral community was generally dominated numerically by ostracods, in particular *Kennethia cristata* and *Newnhamia* sp , and the amphipod *Austrochiltonia* spp. The zooplankton community, depending on lagoon, was dominated by the calanoids and/or

daphniid cladocerans as per Chapter 4

The copepod fauna in Cape Naturaliste No. 1 were not identified to species level The calanoids and cyclopoids are composite groups of different taxa (**Figure** 6.3.A). The different peaks in numbers throughout the year possibly representing responses of different species within these taxonomic groups to environmental cues. In numbers the calanoids were codominant with many of the chydorid taxa. Amphipods of the genus *Australochiltonia* displayed a bimodal temporal distribution with a spike in abundance in mid summer (7 individuals/l) and with an increase in winter (5 individuals/l), numbers falling in autumn and spring The cladocerans were represented by 4 taxa (**Figure** 6.3.B). *Ilyocryptus*, in low numbers, was transiently present in autumn, followed by *Bosmina meridionalis* present only during mid winter and also in low numbers *Ceriodaphnia* and *Simocephalus* appeared to be mutually exclusive The rise and fall in the former followed by those of the later. Six species of ostracods were identified from Cape Naturaliste No. 1. Numbers were too few to readily identify anything except for broad trends for three species (**Figure** 6.3 C). *Limnocythere* was present but only one individual was recorded on each occasion it was present Both *Cypretta* and *Ilyodromus cf. candonites* were present throughout much of the year. In contrast *Gomphodella sp.* and *Kennethia cristata* were present in 'high" numbers during winter, whereas *Newnhamia sp.* appeared to favour conditions in summer (**Figure** 6.3.D). All three species were transient and successive in appearance with *Kennethia* increasing in late spring-early summer and again in late summer, followed by *Gomphodella* and then *Newnhamia.* The chydorids in Cape Naturaliste No. 1 tended to display distinct peaks in abundance. *Alona* spp. was present throughout the year in relatively low numbers, then increased in abundance during the summer months reaching a maximum of 4 individuals/l overlapping *Ephemeroporus* (**Figure** 6.4.A). The decline in *Alona* and *Ephemeroporus* was followed by a rise in *Rak. Alonella* spp and *Camptocercus australis* were present in low numbers with the former reaching a peak in abundance late spring and in early winter (**Figure** 6 4.B). In contrast *Chydorus* spp was present throughout the year in relatively significant numbers and "bloomed" during the summer months with a maximum of 25 individuals/l (**Figure** 6.4.C).

In Blackmans Lagoon the chydorids were present mainly during the autumn (**Figure** 6.5.A-B). Temporal ranges all overlapped and all taxa shared an increase in numbers during late summer to autumn, disappearing by the end of June. *Camptocercus australis* and *Dunhevedia crassa* were briefly present, but overshadowed by *Pleuroxus* sp. and *Graptoleberis testudinaria. Alona* spp., *Alonella* spp. and *Chydorus* spp. showed a similar temporal abundance with numbers increasing slightly during autumn and falling by winter. All of these taxa were present in very low numbers, <1 individual/l. In contrast to the chydorids, *Boeckella symmetrica* and *Australochiltonia* spp. were present in significant numbers (**Figure** 6.5.C). Both taxa displayed a numerically bimodal temporal increase in abundance within Blackmans Lagoon. Numbers of *Australochiltonia* spp. peaked in autumn (17 individuals/l), then again in spring (>30 individuals/l). *Boeckella symmetrica* showed a similar rise and fall in late summer-early autumn (>25 individuals/l) and followed by a winter maximum of >45 individuals/l. The daphniids, *Ceriodaphnia* and *Simocephalus* (**Figure** 6 5 D) appeared to be mutually exclusive with the peak in abundance in the later (>4 individuals/l) occupying a trough of the former taxa. *Daphnia* seemed to be present throughout the year but in low numbers, whereas *Macrothrix* was transient in appearance. Both taxa were recorded in low numbers (<1 individual/l).

Little Waterhouse Lake contained six taxa of ostracods that were analysed quantitatively.

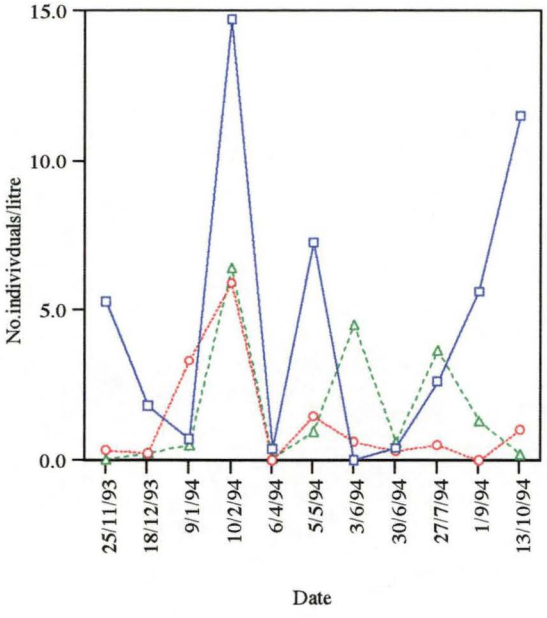


Figure A

- Calanoida
- Cyclopoida
- Austrochiltonia spp.

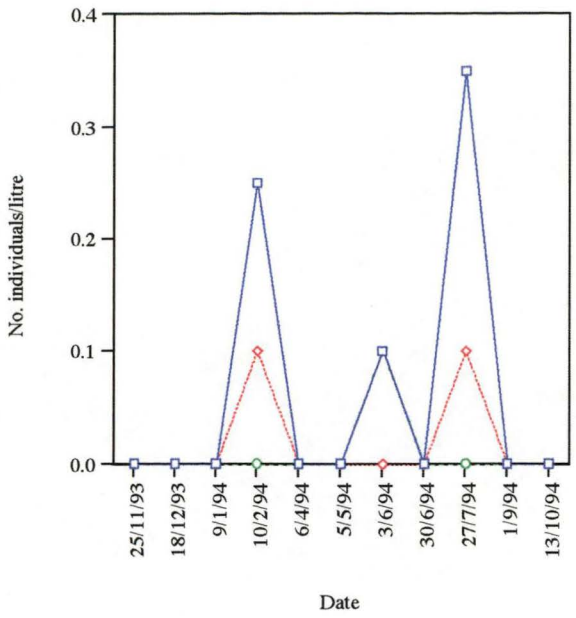


Figure C

- Cypretta spp.
- Ilyodromus cf. candonites
- Limnocythere cf. mowbrayensis

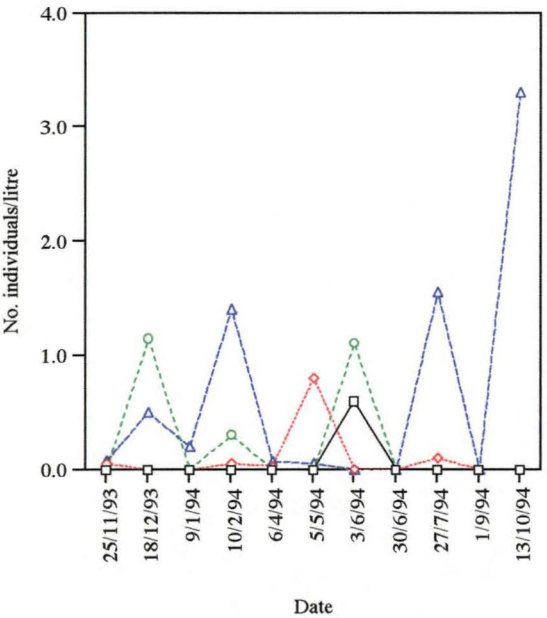


Figure B

- Bosmina meridionalis
- Ilyocryptus sp.
- Ceriodaphnia sp.
- Simocephalus sp.

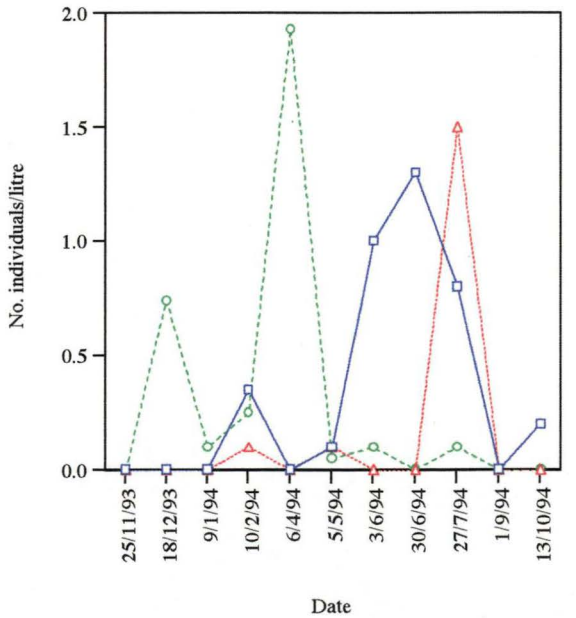


Figure D

- Kennethia cristata
- Gomphodella sp.
- Newnhamia sp.

Figure 6.3 Cape Naturaliste No. 1 Quantitative microcrustacean samples 1993-1994

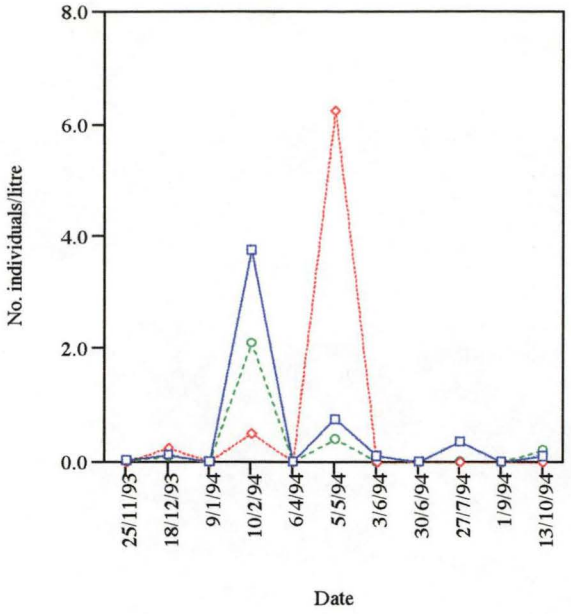


Figure A

Alona spp.

Rak sp.

Ephemerporus sp.

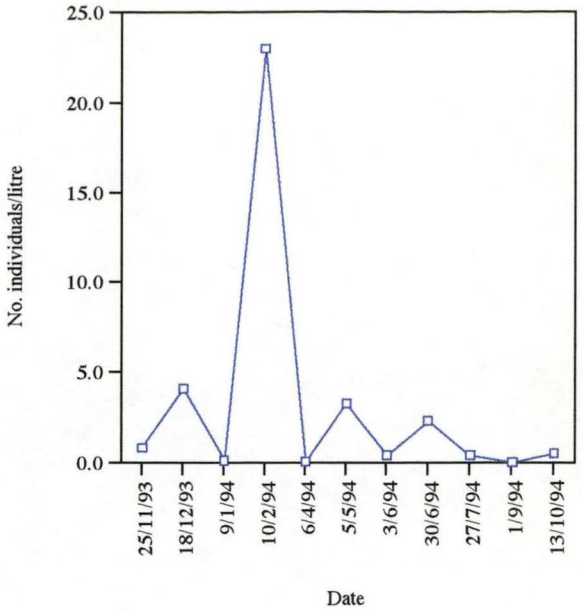


Figure C

Chydorus spp.

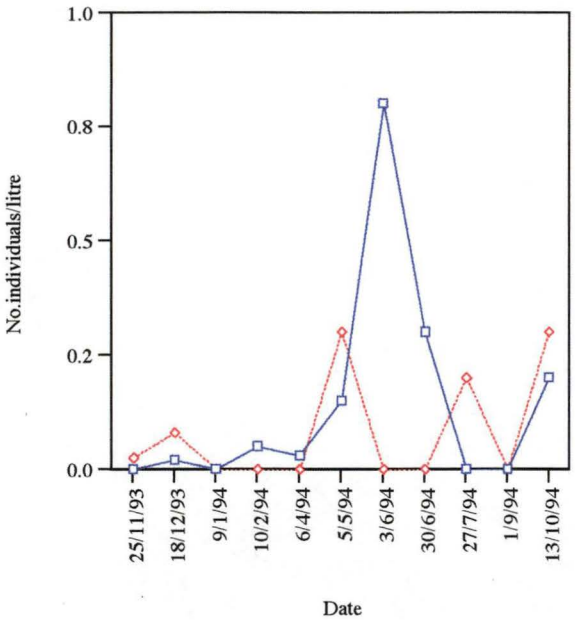


Figure B

Alonella spp.

Camptocercus australis

Figure 6.4 Cape Naturaliste No. 1 Quantitative microcrustacean samples.

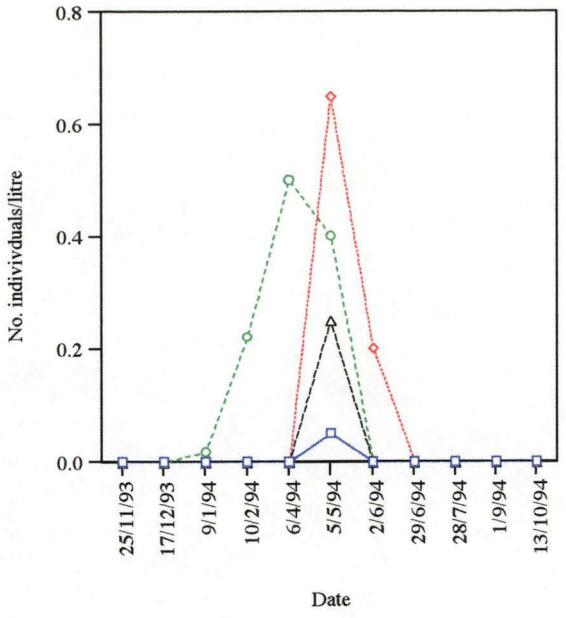


Figure A

- Camptocercus sp.
- Grapteloleberis sp.
- Pleuroxus sp.
- Dunhevedia sp.

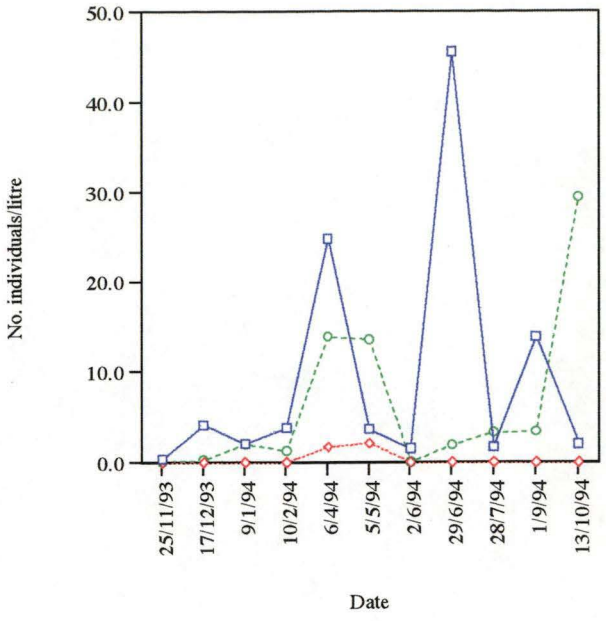


Figure C

- Boeckella symmetrica
- Cyclopoida
- Austrochiltonia spp.

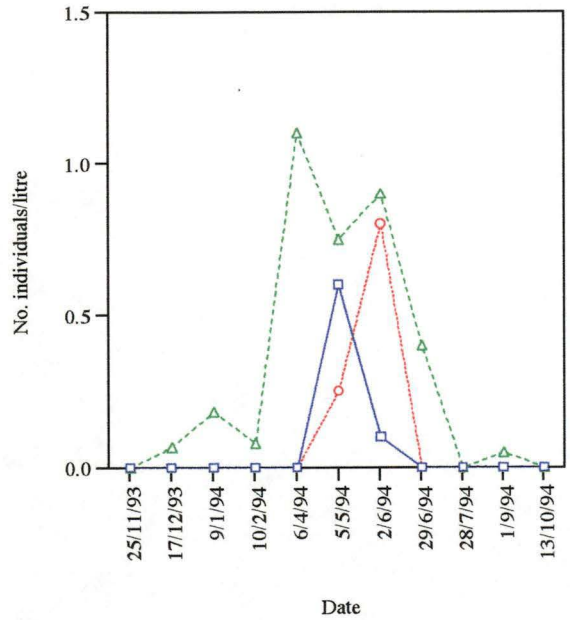


Figure B

- Alona spp.
- Alonella spp
- Chydorus spp.

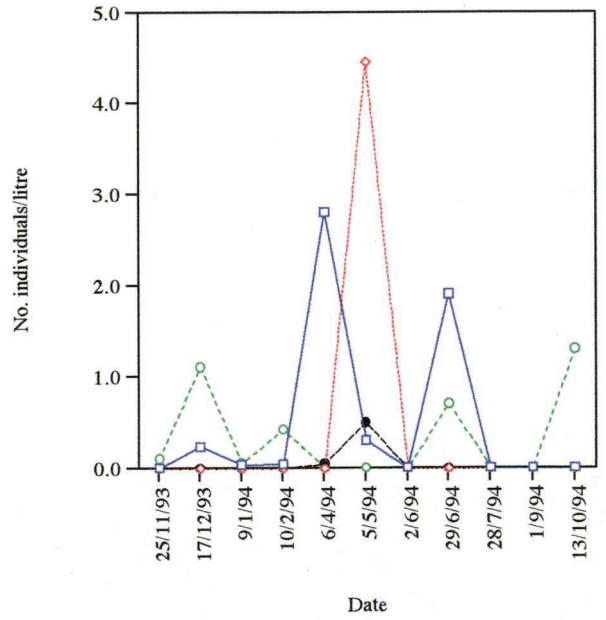


Figure D

- Ceriodaphnia sp.
- Simocephalus sp.
- Daphnia sp.
- Macrothrix sp.

Figure 6.5 Blackmans Lagoon microcrustacean quantitative sample. 1993-1994

Numbers were too few to readily identify anything except for broad trends for some species (**Figure** 6.6.A). *Cypretta* spp. was present but only one or two adult specimens were recorded on each occasion it was present. *Ilyodromus cf. candonites* were present in 'high" numbers during winter, whereas *Newnhamia* sp. appeared to favour conditions in summer (**Figure** 6.6 A). All three species were transient and successive in appearance In contrast *Gomphodella* sp. (**Figure** 6.6.B) was transiently present in "moderate" numbers during winter (>5 individuals/l), whereas *Limnocythere mowbrayensis* appeared to prefer conditions in winter *Kennethia cristata* was present in "high numbers throughout the sampling period relative to the other taxa, progressively increasing in abundance during the study period, reaching "bloom" conditions of >150 individuals/l at conclusion of the study. The calanoid copepods *Calamoecia australis* and *Calamoecia gibbosa*, and *Macrothrix* spp. were transient in appearance and few in number (**Figure** 6.6.C). In contrast *Boeckella symmetrica*, was present throughout the year, with numbers showing a decrease in winter. *Daphnia* was present only during the later stages of the study, and also in low numbers. The chydorids *Alona* spp. and *Chydorus* spp. (**Figure** 6 7.A) were present through out the year with both showing a bimodal temporal increase in abundance *Chydorus* increased in number during summer then fell in number, showed a slight rise during winter, then increased again during the following spring. *Alona sp.* displayed a similar profile but the initial increase followed the decline of *Chydorus*. In contrast to *Alona* spp and *Chydorus* spp., *Alonella* spp. showed a decline in summer, with an increase in winter (<12 individuals/l), followed by a slight drop in number, but this second decline was then followed by a dramatic increase ((40 individuals/l) All three taxa in Little Waterhouse Lake showed an increase in number in October 94. In contrast, *Dunhevediacrassa* and *Graptoleberis testudinaria* (**Figure** 6.7.B) were more erratic in number, and appearance. The cyclopoids showed a dramatic increase in number during winter. *Austrochiltonia* showed an erratic but continual increase in abundance over the year (**Figure** 6.7 C) Both *Ceriodaphnia* and *Simocephalus* showed a slight rise in number during February 94 (**Figure** 6.7.D). The former taxon was present during summer before becoming absent from the faunal assemblage. In contrast *Simocephalus* was present through out the year. *Bosmina meridionalis* was both transient and dramatic in appearance. It was recorded only once in Little Waterhouse Lake but in high numbers (30 individuals/l).

The microcrustacean population densities observed in situ in this study should be treated with caution. The variation in population densities between samples from different weedbeds and the lack of truly quantitative sampling of limnetic microcrustaceans, limit the value of the observations obtained They do seem to indicate though, that littoral microcrustaceans attain higher densities than do limnetic microcrustaceans.

6.7 DISCUSSION

When compared to the amount of work done on entomostracan zooplankton from open water habitats, little attention has been paid to the ecology of fauna within aquatic macrophyte communities. Reasons for the lack of quantitative work on these organisms include the difficulties in sampling, and subsequent sorting, of these very heterogeneously distributed animals. Population studies of similar fauna are more readily made in the relatively simple habitat structure of open water.

The well vegetated lagoons with submerged and emergent aquatic macrophytes tend to have a

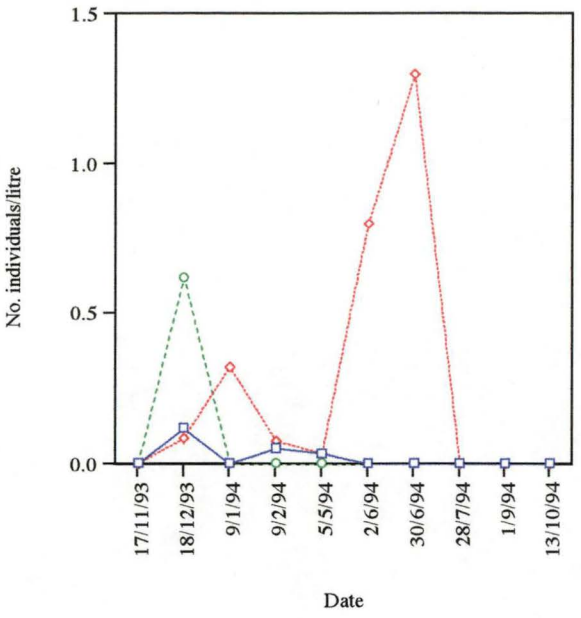


Figure A

Cypretta spp.

Ilyodromus cf candonites

Newnhamia sp.

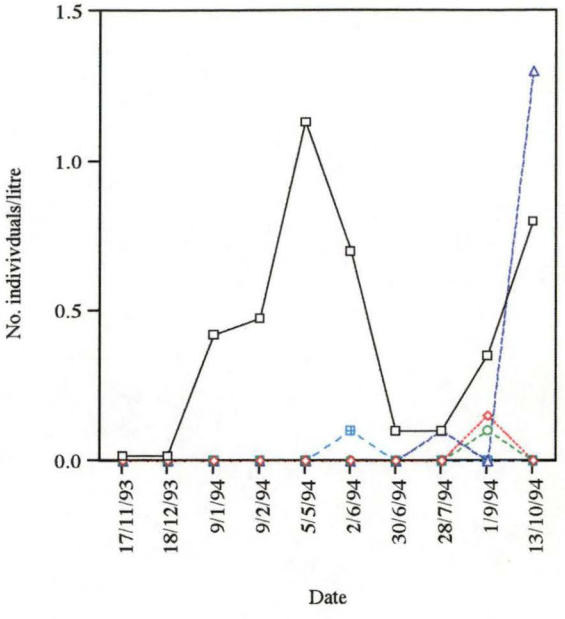


Figure C

Boeckella symmetrica

Calamoecia australis

Calamoecia gibbosa

Daphnia sp.

Macrothrix spp.

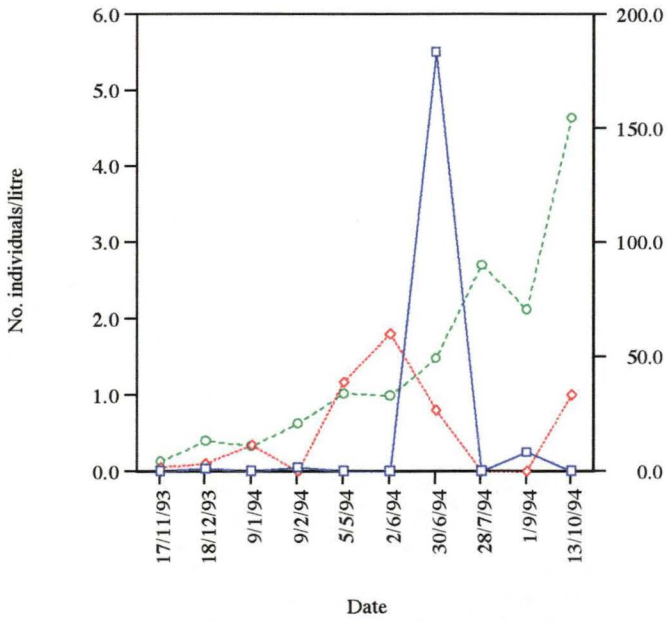


Figure B

Gomphodella cf australica

Limnocythere mowbrayensis

Kennethia cristata *

* Refers to graph right hand side scale

Figure 6.6 Little Waterhouse Lake Quantitative microcrustacean samples. 1993-1994

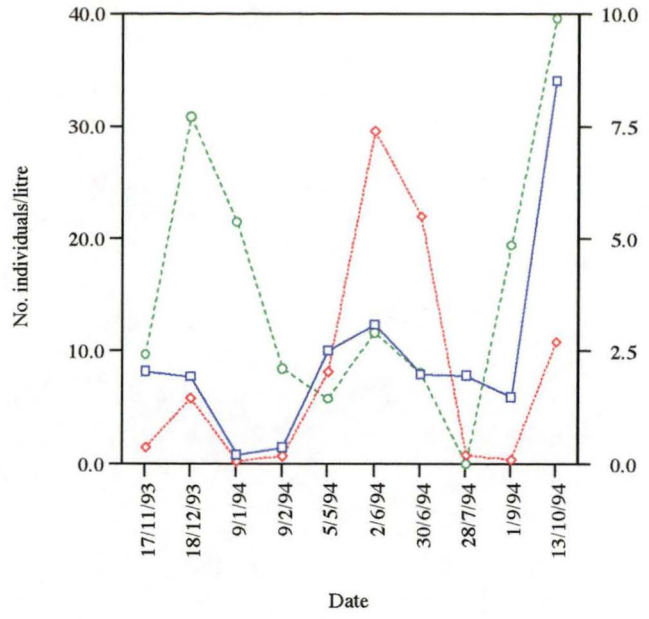


Figure A

Alonella spp.

Alona spp. *

Chydorus spp. *

* refers to right hand side of graph

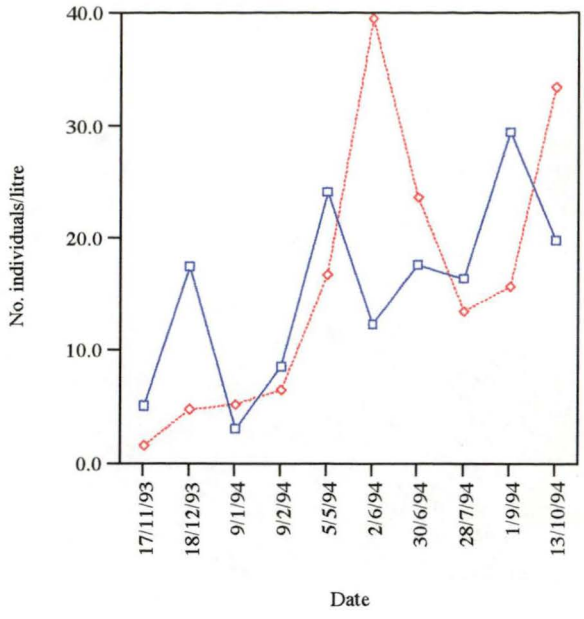


Figure C

Austrochiltonia spp.

Cyclopoida

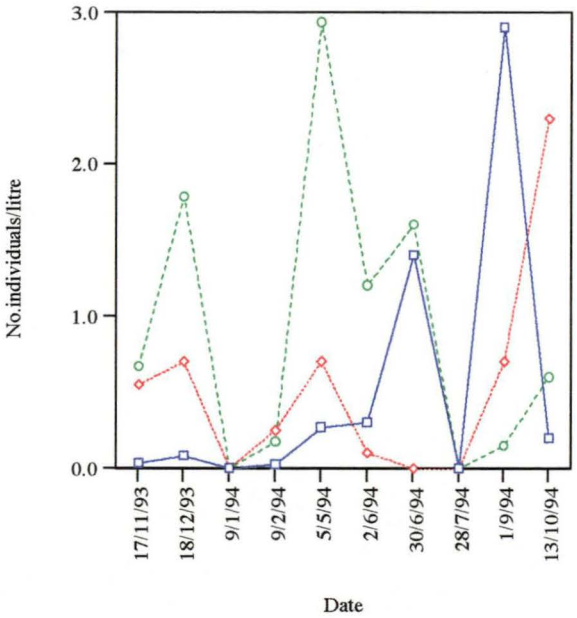


Figure B

Camptocercus australis

Dunhevedia crassa

Grapteloleberis testudinaria

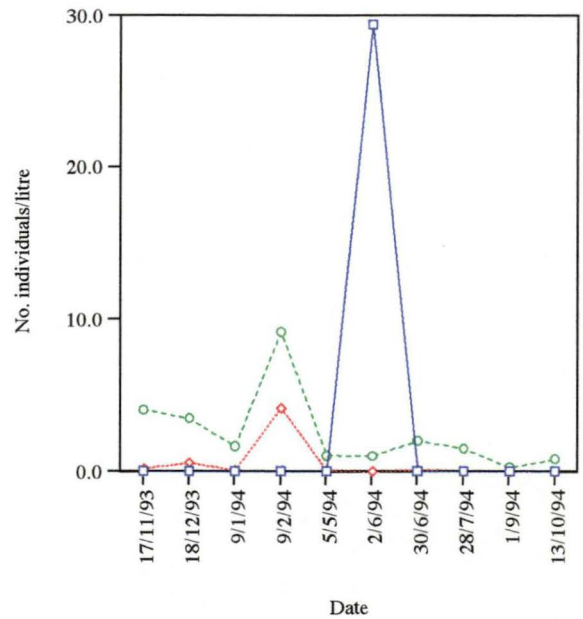


Figure D

Bosmina Meridionalis

Ceriodaphnia sp.

Simocephalus sp.

Figure 6.7 Little Waterhouse Lake. Microcrustacean quantitative samples. 1993-1994

significantly higher species diversity. Thus these lagoons most closely resemble each other in community composition. The aquatic vegetation provides a diversity of habitats which are not available in open water. The shallow littoral zone of these lakes is a heterogeneous environment where the presence of different species of aquatic plants creates a complex of adjacent and overlapping habitats (Hillman 1986; Cyr & Downing 1988; Irvine *et al.* 1990; Pontin & Shiel 1995)

The majority of microcrustacean species found in this study occurred among aquatic macrophyte weedbeds. This species richness may be aided by the marked seasonal variation in the aquatic environment brought about by the seasonal climate Studies on the mainland of Australia have shown that seasonal drying and reinundation also contribute to species diversity (Mckaige 1980; Watson *et al.* 1995; Pontin & Shiel 1995). This mechanism is put forward as a possible explanation for the high species diversity in Cape Naturaliste No. 1 In the shallow lagoons of the North East, the alternating water levels on a seasonal and yearly basis influence habitat heterogeneity The expansion of the aquatic environment in the Wet season with the associated proliferation of aquatic macrophytes, creates an extensive range of physical sites that can be exploited by littoral microcrustaceans. Plant morphology is highly plastic: Wide variations in surface area to biomass ratios and in form of various macrophyte species (compare *Eleocharis* spp. or *Triglochin* sp. with *Myriophyllum* or *Potamogeton* sp.), along with differences in physical factors (exposure to different turbidity, different water depths, etc.), provide a variety of sites and microhabitats to suit different epiphytic and epibenthic microcrustacean species.

Big Waterhouse Lake and Little Waterhouse Lake were the two most similar sites. Both of these lagoons had extensive areas of dense and complex structured aquatic macrophyte communities. Water levels in these lagoons, though variable, did not expose large areas of the littoral macrophyte sediments. Large dense stands of *Myriophyllum* spp , *Potamogeton* spp., *Typha* sp , *Eleocharis* sp. and *Triglochin* sp. would have acted to reduce horizontal water mixing and transport of plankton between littoral and limnetic zones (Kairesalo 1980) The differing plant morphologies may also have influenced microcrustacean community composition and species abundance

Microinvertebrate abundance varies between different aquatic macrophyte species (Campbell & Clarke 1983, Cyr & Downing 1988). Plants with dissected branching leaves and stems are generally thought to support higher species diversity and abundance than broad-leaved plants, as branched leaves provide more substrate and increased levels of periphytic algae, accumulate more particulate matter, provide more surface area, and protection from predators. Microhabitat spatial heterogeneity may also be influenced by the density of the macrophyte community (Irvine *et al.* 1990) and leaf condition. Senescence of leaves has been shown to influence microcrustacean abundance (Campbell & Clarke 1983).

Microcrustacean zooplankton are an important component of the aquatic ecosystem in the North East wetlands. They have few intrinsic regulatory mechanisms with which to counter environmental changes they are therefore likely to be affected by habitat disturbance, both natural and man made. These naturally occurring environmental changes in the temporary and astatic waterbodies of the North East, are probably a major contributing factor for the high species diversity and change in community composition observed. This is particularly true for Cape Naturaliste Lagoon No. 1. This shallow astatic-ephemeral lagoon possesses a sparse macrophyte community, simple in structure, small in area, and restricted to the deeper part of the lagoon basin. Its high species diversity but relatively low abundance is attributed to the "instability " of the lagoon

environment. As the Dry season progresses and water levels fall, many weedbeds die down, and hence there is a reduction in suitable habitats for littoral microcrustaceans.

The lower species diversity and abundance (in particular of the chydorids) in Blackmans Lagoon when compared to Big and Little Waterhouse Lakes, may, in part, be attributed to the lower density and paucity of the aquatic vegetation, and thus increased horizontal mixing of the littoral water column in Blackmans Lagoon (Sollberger & Paulson 1992). Common littoral microcrustacean species in Blackmans Lagoon are poorly represented in the littoral zone which is lacking or has simple macrophyte communities. In such areas, species composition and abundance resembles that of limnetic areas. (Smyly 1952; Smirnov 1963; Straskraba 1964; Stolbunova & Stolbunov 1981, Lemly & Dimmick 1982a,b). This may explain the relative absence of ostracods and chydorids in Blackmans Lagoon.

The low species diversity for Bowlers Lagoon and absence of calanoids, amphipods and large bodied cladocerans may be explained by several mechanisms. 1) Low O_2 concentrations in water amongst the weed beds may have important sub-lethal effects. Depressed filtering rates in Daphnia have been recorded for *Daphnia* in O_2 concentrations of 3 mg/l^{-1}. Bowlers Lagoon consistently had bottom waters with low O_2 levels and once had anoxic conditions (Chapter 5). 2) H_2S produced under anaerobic conditions in bottom waters where there is very dense submerged macrophytes and organic debris (as in Bowlers Lagoon) may be differentially toxic to differing species and may explain observed distributions (Kring & O'Brien 1976) 3) Physical conditions prevalent in dense submerged plant communities may be detrimental to species through a reduction in available habitat space (Irvine *et al.* 1990).

Variability in zooplankton horizontal distribution, however, may be greatly influenced by environmental conditions other than just aquatic vegetation Advection currents generated by wind may concentrate plankton in down wind areas along lake edges (George & Edwards 1976, Hart 1976). This phenomenon was noted in the field for several of the Cape Portland Lagoons (Chapter 4), and in particular Blackmans Lagoon, in this study. Blackmans Lagoon has a simpler and sparse macrophyte community than the other lagoons and has relatively larger areas of open water. Therefore the area of the littoral zone is smaller and with low structural complexity Wind generated currents may easily mix inshore and offshore waters, aiding in the transport and mixing of zooplankton communities.

Fish predation can also influence zooplankton horizontal distribution. Limnetically associated taxa may occupy the periphery of a lake as a result of large numbers of predators and the ability to feed more efficiently in open waters than amongst macrophyte stands (Cryer & Townsend 1988). Blackmans Lagoon, Big and Little Waterhouse Lakes are all stocked with introduced salmonids, in addition to a number of native fish species.

The availability of suitable food and microhabitat is of importance in determining horizontal distribution and population densities of microcrustaceans (Campbell & Clarke 1983; Sollberger & Paulson 1992). Different plant species may have leaves more "attractive" than others to organisms and therefore contribute to microhabitat spatial heterogeneity (Campbell & Clarke 1983). The abundant epiphytic growth in the weedbeds is likely to be a significant source of food for littoral microcrustaceans. The condition of the leaf also has been shown to influence population abundance (Campbell & Clarke 1983). These authors found *Ceriodaphnia* prefers senescent leaves with low algal density, which is not unexpected as this cladoceran is a swimmer and filter feeds on

phytoplankton and small suspended particles. *Simocephalus* is also a filter feeder but when feeding attaches to substrates, including leaves, regardless of their microhabitat condition. *Ephemeroporus* sp., *Alona* sp., cyclopoids and ostracods preferred decaying or senescent leaves and this may indicate that these microcrustaceans feed on bacteria, protozoa, or plant debris associated with decomposing leaves.

Abundance of zooplankton does not always correlate with the abundance of phytoplankton Zooplankton may be very abundant when phytoplankton are virtually absent (Moss 1980). Ciliates protozoans are believed to serve as an important link between microcrustacean plankton and bacteria in freshwaters (Porter *et al.* 1979). The concept of the "microbial loop" (Tranvick 1992) originally applied to marine waters, but is equally applicable to freshwaters with some differences Cladocerans and particularly rotifers are efficient bacterioplankton graziers (Boon & Shiel 1990), virtually absent in marine waters but are ubiquitous in fresh waters Also DOM in freshwaters is in much higher concentrations in freshwaters due to allochthanous DOM released from the soil and run off. These humic lakes have a high bacterial biomass (Salonen 1981; Hessen 1985) and in Australia such humic lakes support a great diversity of rotifers (Shiel *et al.* 1989). The DOM-bacterial-protozoan pathway when added to the conventional food chain is to greatly increase the trophic levels within fresh waters.

In short it is likely that the diversity of microhabitats and food sources occurring within the weed bed habitats contributes to the species richness and population abundance of microcrustacean communities in the study area. Analysis of individual species diet would help to determine the degree of competitative exclusion. However though different species may consume a similar diet, life style may reduce competition by temporal separation of the species

The life history of cladocerans, and to a certain extent copepods, is shaped by their existence in shallow freshwaters which may dry up (Hutchinson 1967) Cladocerans cope with the seasonal increase in water temperatures, drying of their environment or loss of food by producing resting eggs (following sexual fertilisation) which are surrounded by a thickened brood chamber called an ephippium. These resting eggs are able to resist desiccation and lie dormant until favourable conditions return. When their habitat is next inundated the resting eggs hatch, producing females which then reproduce parthenogenetically. As almost the entire population is composed of females that have the ability to produce viable mature offspring, there is greater potential for rapid population growth during the relatively short periods when conditions are favourable. In the wetlands of the North East, short generation times are induced by the high summer water temperatures. When conditions deteriorate, males are usually produced and these fertilise eggs within the ephippial females, which are then deposited in the ephippium.

The daphniid *Daphniacarinata* like *Ceriodaphnia* appears to favour the relatively more stable environments of the permanent waterbodies. It is present throughout the cooler months of the year in those lagoons from which it was recorded This is in keeping with records from the mainland where populations die out during the warmer temperatures of summer. The shallow lagoons of the north eastern wetlands contract via evaporation during summer, with a reduced volume of water to heat, the lagoons experience high water temperatures in excess of 25^{o}C (Chapter 5). Elevated temperatures common in these lagoons during summer pervade zooplankton ecology directly and indirectly, and have been reviewed by Moore *et al.* (1996). The species survives in the respective water bodies as a sexually produced egg encased in an ephippium. This 'resting stage' hatches when

more favourable cooler conditions are present. Winter water temperatures vary from 4°C to 12°C (Chapter 5).

Copepods rely on sexual reproduction which leads to slower population increase than parthenogenetic reproduction, because only half of the population can produce progeny. Eggs are carried in egg sacs attached to the urosome of the female, and hatch into small larvae known as nauplii. There are five to six naupliar stages and six copepodite stages before the adult form is assumed, in the sixth copepodite stage (Hutchinson 1967). Population growth in copepods is more dependant on the survival rates of various immature stages than on egg production. Although copepods have considerably slower generation times than cladocerans, copepods have an advantage in that the naupliar stages generally don't compete with their adult stages for food as they consume different-sized particles (Le Cren & Lowe-McConnell 1980).

6.8 CONCLUSIONS

The microcrustacean species (especially the calanoids) occurring within the coastal wetland of the North East Coastal plain form a very rich assemblage in comparison with those of other areas of Australia (Shiel 1976; Morton & Bayly 1977; Lake *et al.* 1989). This is probably due to the marked seasonal variation in the aquatic environment of this region brought about by the winter rainfall.

Water levels of these lagoons fluctuate considerably and as a result shorelines are rather indefinite, dependent upon basin morphometry, season and severity of the summer. Water levels are determined by rainfall-evaporation relationships and the internal seepage patterns of the lagoon basin and catchment. The expansion of the aquatic environment in the 'Wet season', with the associated proliferation of aquatic macrophytes, creates a wide range of physical habitats for littoral microcrustaceans. As water levels fall with the progression of the summer, weedbeds decline and lagoons and other waterbodies contract or dry out on the coastal plains Littoral species assemblages decline because of lack of suitable habitats, and open water species assemblages reform after cessation of the high water flow rates of the Wet season

The taxonomic diversity of the microcrustacean community may be viewed as a paradox analogous to the "paradox of the plankton" identified by Hutchinson (1961), who showed a contradiction between theoretical population ecology (principle of competitive exclusion) and empirical data (plankton generally comprise a large number of species, occupying the same niche). The paradox of high species diversity in this instance may be similarly solved. For competitative exclusion to occur, the competing populations are required to operate within constant environmental conditions. However the littoral environment is disturbed in different ways (temperature, turbidity, fluctuations in water chemistry and water level, variable conductivity) on a time scale short enough to alter the habitat of competing microcrustacean populations before competitive exclusion occurs. Additional mechanisms such as differing life cycles, mortality rates, predation, growth rates and the occurrence of littoral microhabitats all encourage co-existence of populations. The spatial and temporal structuring of planktonic communities into microzones of different niches would further compliment the parallel existence of different populations.

Each lagoon differs from its close neighbour in community response to environmental cues experienced in each lagoon. The NE shallow coastal lagoons are dynamic systems in a constant state of flux.

CHAPTER 7

LIMNOLOGY OF THE WEST COAST LAGOONS WITH REFERENCE TO THE MICROCRUSTACEA

7.1 ABSTRACT

The dystrophic lagoons of the West Coast lack a well defined littoral zone, have relatively simple macrophyte communities, are deep relative to surface area and have stable waterlevels and relatively definite shorelines. Therefore niche diversity, and as a consequence microcrustacean species diversity, is low. The West Coast lagoons are hydrologically stable habitats. Seasonal fluctuations in the hydrology of these lagoons do not affect their ecology to the same degree as the NE lagoons - i.e. a small change in depth is not associated with a large change in surface area and volume, nor with a concomittant change in the physical and physicochemical environment. This stability would reduce niche and spatial habitat heterogeneity. The relative paucity of the microcrustacean fauna is in marked contrast to the rich assemblage of rotifer fauna (Koste *et al.* 1988) and that of the microflora (Bowling *et al.* 1993; Tyler 1996), and is in contrast to that recorded for the microcrustacea in dune lakes of NE Tasmania.

7.2 INTRODUCTION

A notable cluster of coastal lagoons occurs in the Macquarie Harbour-Ocean Beach area of the West Coast of Tasmania, located north of the township of Strahan and inland from Ocean Beach (**Figure** 7.1). The coastline to the West and Northwest of Macquarie Harbour is an uninterupted curved beach 32 km in length (**Plate** 12). Ocean Beach, south of the Little Henty and Henty Rivers, is almost straight with a North-South aspect. There are small soaks draining the sand dune country to the east of the beach. The southern end of Ocean Beach curves sharply and continues into Macquarie Harbour.

Behind the beach, extending up to 7 km inland, is a large, complex, vegetated, but eroded Pleistocene parabolic sand dune system. The source of sand for these dunes is believed to be silicoeus, glacial and glacifluvially-derived sediments from the granitic lower gorge of the Little Henty and Henty Rivers (Banks *et al.* 1977). A number of Holocene, unvegetated, active, transgressive dunes occur immediatly behind the beach, advancing inland at the rate of 17 m per year. The source of sand for these dunes is from the current beach and also from blow-outs of the older Pleistocene dunes.

There is a distinct contrast in degree of soil development between the the unvegetated, active dunes behind the beach and the fully vegetated dunes further inland which rise to 145 m in altitude and have a height of 90 m north of the township of Strahan (Banks *et al.*, 1977). Within the vegetated Pleistocene series there is a number of major dunes each with complex blow-outs and longitudinal ridges. These become progressively more complex and dissected to the south east of Ocean Beach, but north of Strahan.

The progressive development and increase in depth of the soil profile with increasing distance inland from the beach suggests a progressive increase in age of the dunes. This implies a source of sand different from today, i.e. the Henty River. The age of dune building for Ocean Beach (Banks *et al.* 1977) is thought to be similar to that in North East Tasmania (Bowden 1978, 1983), King Island (Jenning 1959; 1961), Flinders Island (Kershaw & Sutherland 1972) and Bruny Island (Banks *et al.* 1977).

There are a number of active dunes, both vegetated and unvegetated, inland from the beach. Many of these are complex and interfere with one another. It is believed the unpredictable nature of the wind direction may be in part responsible as Strahan records daily one of the widest ranges of

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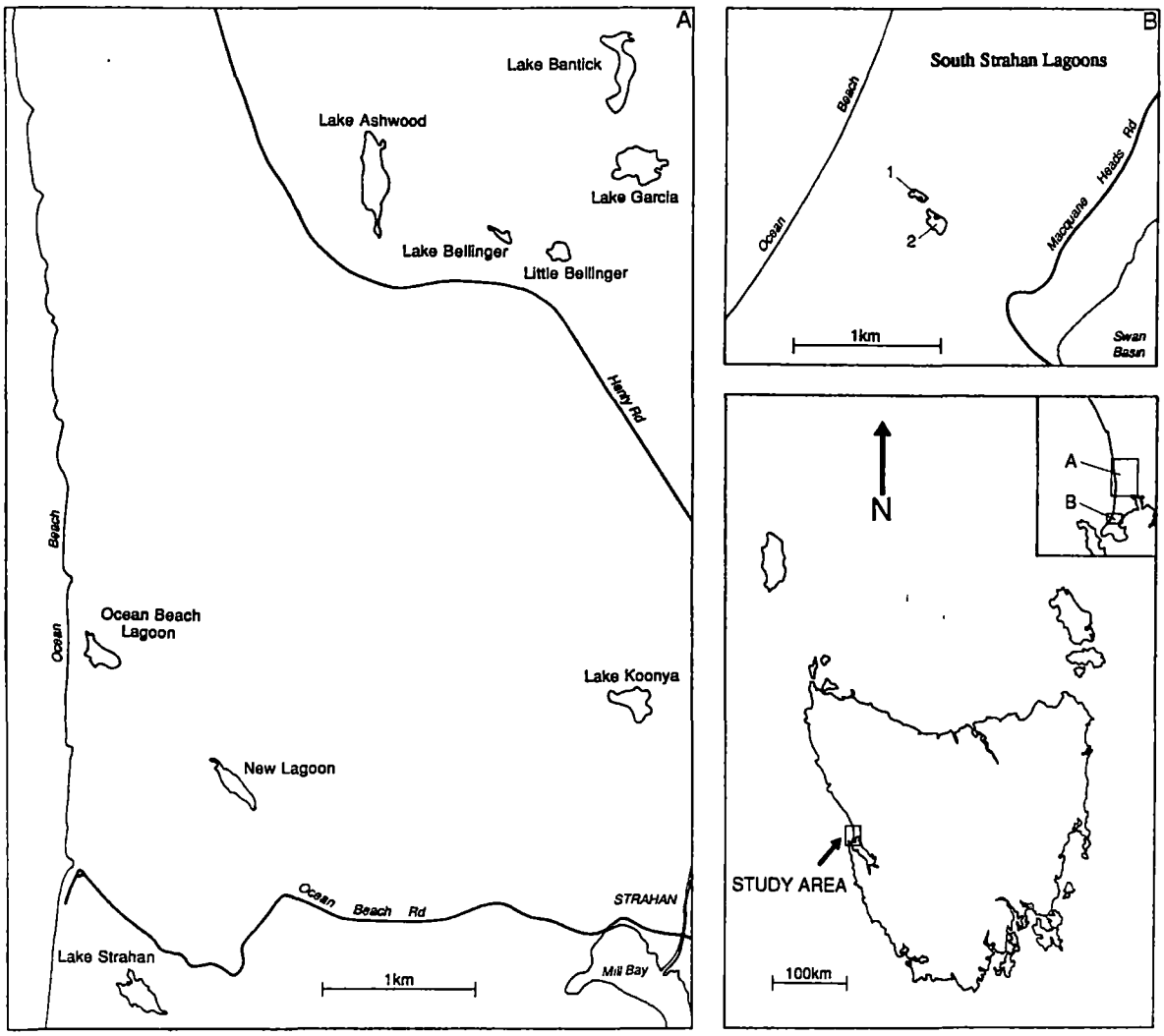


Figure 7.1 Location of study sites on the West Coast of Tasmania

direction of strong winds of any Tasmanian coastal weather station.

The West Coast of Tasmania experiences the brunt of the westerly wind regime with a cool and changeable maritime climate. Total precipitation is considerable (**Figure** 7.2), enhanced by topography of the western ranges which reach maximum elevations of 1200 m. Maximum orographic rainfall (3600 mm) occurs in these highlands, decreasing westwards towards the coast and eastwards to the inland of Tasmania. There is a seasonal variation in temperature and rainfall with an average annual rainfall of 1500 mm and average number of rain days per year of 240 for Cape Sorell at the mouth of Macquarie Harbour (Nunez 1983).

7.3 AIMS

The aims of the study of the West Coast lagoons were to provide a comparison with those lagoons located on the relatively extensive North East Coastal plain, and Bruny Island By comparing the lagoons from different regions around the state it was hoped to record limnological and biological similarities or significant differences in order to characterise the third limnological province in Tasmania.

7.4 STUDY SITES

The lagoons of the West Coast are, in the main, perched lakes (Timms 1982, type i) lying within longitudinal or parabolic dunes on soils developed in the dunes or on mats of organic matter of low permeability. The South Strahan lagoons (**Plates** 13-14), Lake Garcia (**Plate** 15), Lake Bantic, New Lagoon and Lake Strahan, fall into this catagory being perched 20-100 m above sea level in sand sheets or between dunes of a series of parabolic Pleistocene dunes just north of Macquarie Harbour.

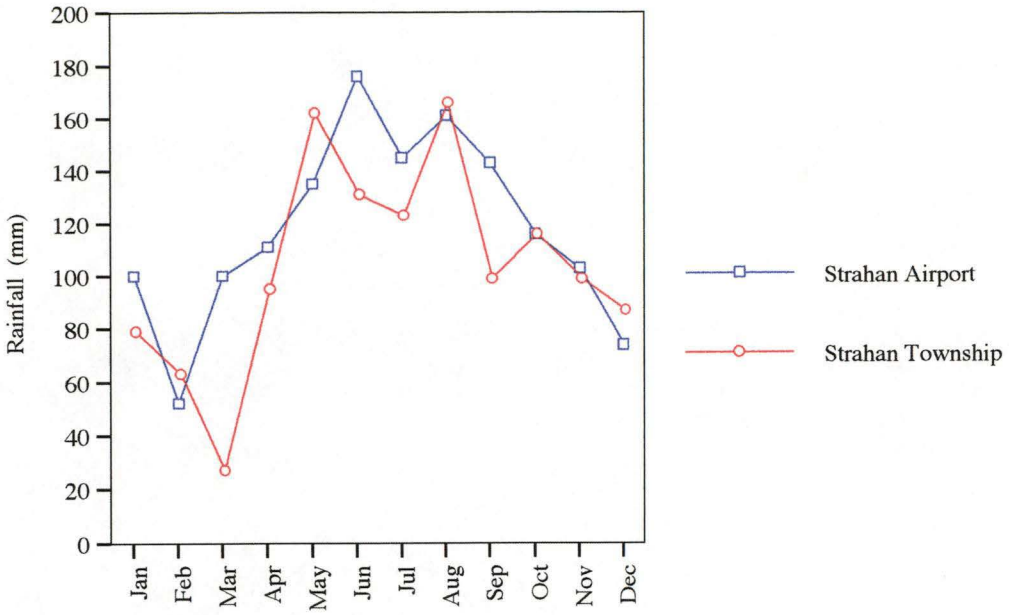
Lake Mallana is a dune contact lake (Timms' type iv). This lagoon is impounded on its seaward side by a transverse dune, but lies on more impermeable rock on its landward sides

The geomorphic origins of Lake Koonya are not included in Timms classification scheme It is a slope-change lagoon where several tributaries draining surrounding dunes and Tertiary sediments emerge onto the upper end of a plain occupied by the lake (Bowling *et al.* 1993). At this change of gradient the volume of water is more than the main stream can discharge, and so it backs up to form L. Koonya.

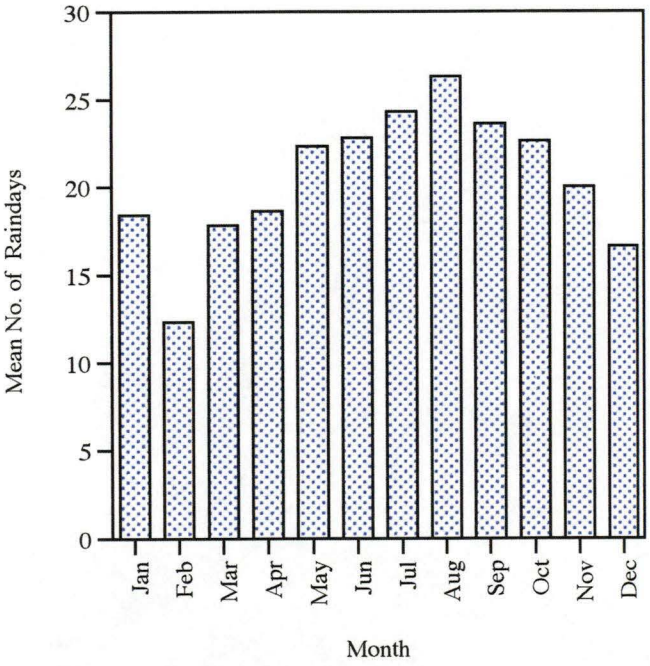
Hibbs Lagoon on the south west coast, 80 km south of Macquarie Harbour, is likewise another lagoon type not included in Timms classification scheme. It was formed by the impoundment of the drowned floor of a river valley by a coastal sand spit, which cut off the lagoon from the sea (Bowling *et al.* 1993).

Parting Creek lake is an artificial lake (**Plate** 16). Water was impounded behind two earthern dams constructed across small creeks draining a button grass moorland. The lake is located within one kilometre of the township of Zeehan and is 30 km inland from Trial Harbour and 40 km North of Macquarie Harbour. The lake was originally built and filled in 1915 and was small in surface area. In 1925 the height of the dams was raised and the depth and the size of the articial lake increased significantly

Lake Cumberland is also an artificial lake with an earthern dam constructed across a small subalpine creek draining a button grass moorland on the slopes of Mt. Cumberland, overlooking Trial Harbour. It was built in the 1890s to provide water for a tin mine and later (1927) for a small



(A) Mean monthly rainfall (in mm) for the period 1981-1995 using all available data (Bureau of Meteorology)



(B) Mean number of raindays for Strahan Airport using all available data 1981-1995. (Bureau of Meteorology).

Figure 7.2 Monthly rainfall and mean number of rain days for Strahan, West Coast of Tasmania

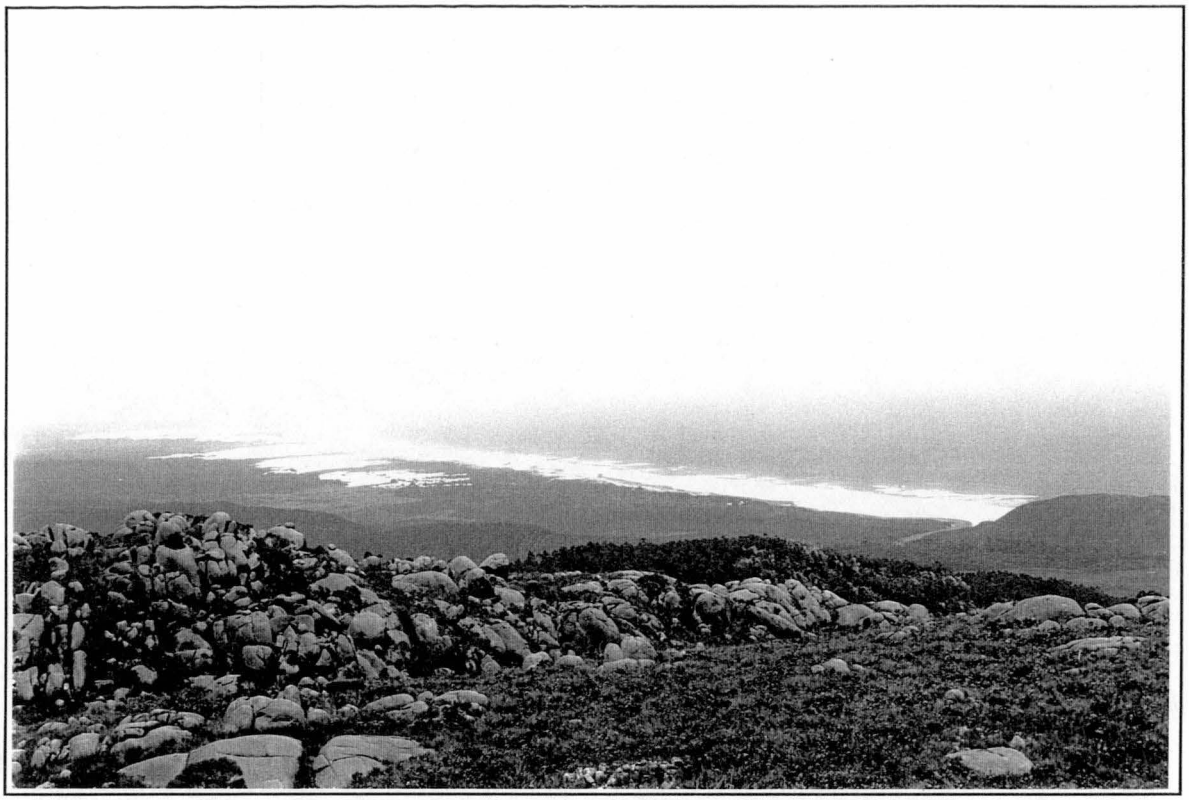


Plate 12. Ocean Beach. The mobile dune systems of Ocean Beach, as seen from Mt. Cumberland are shown to the left of the plate. Trial Harbour is located below the foothills pictured at the right of the plate.

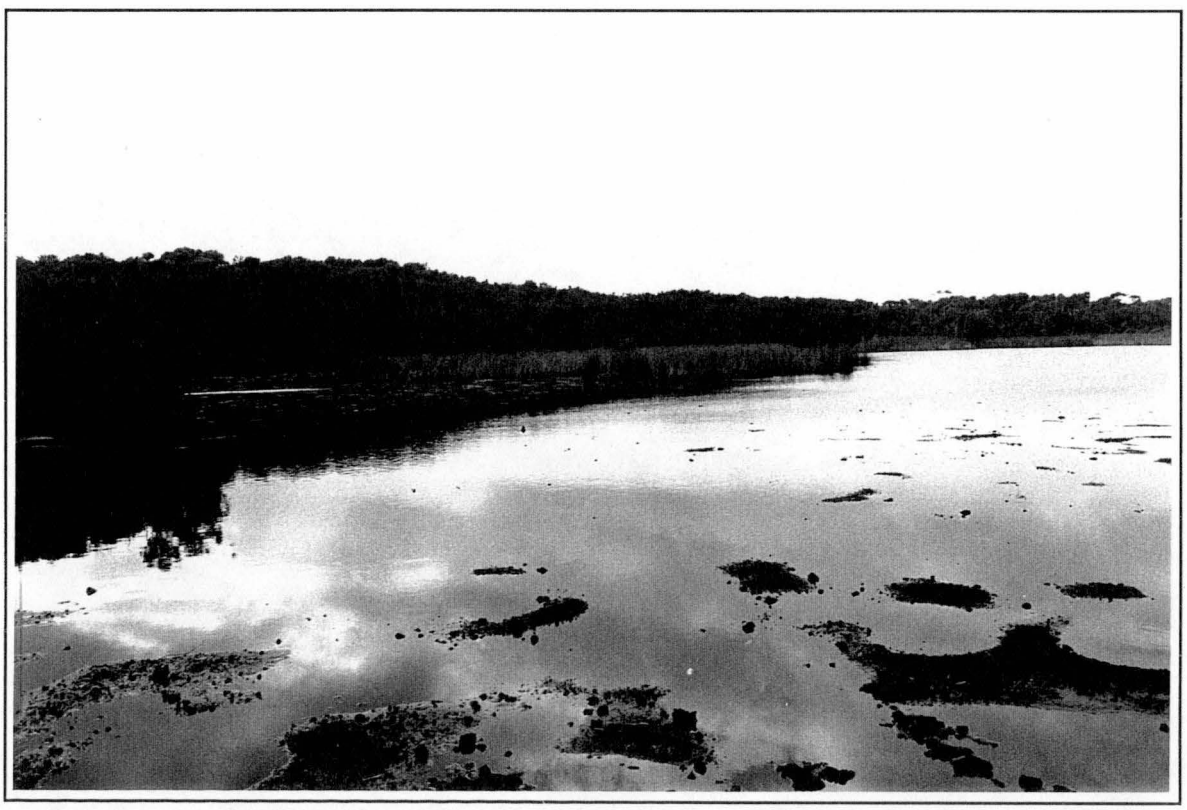


Plate 13. South Strahan Lagoon No. 1.

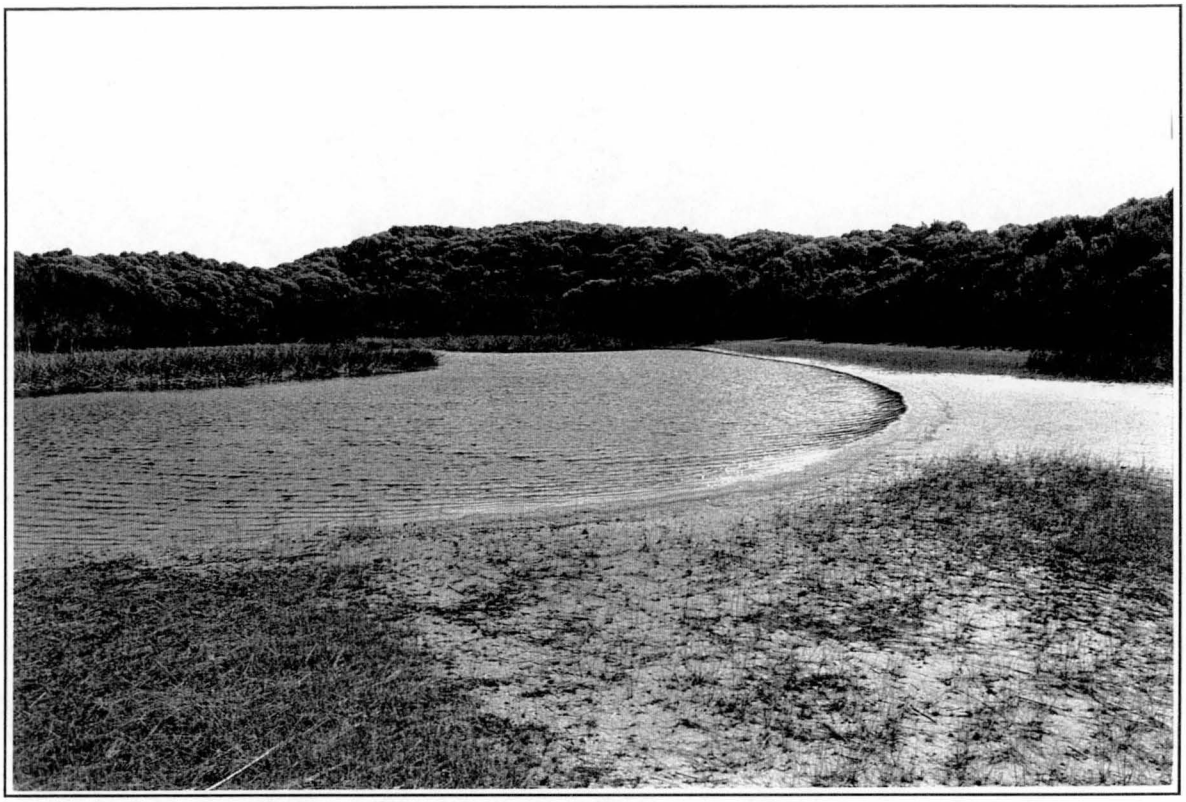


Plate 14. South Strahan Lagoon No. 2.

Plate 15. Lake Garcia. A perched coastal dune lake.

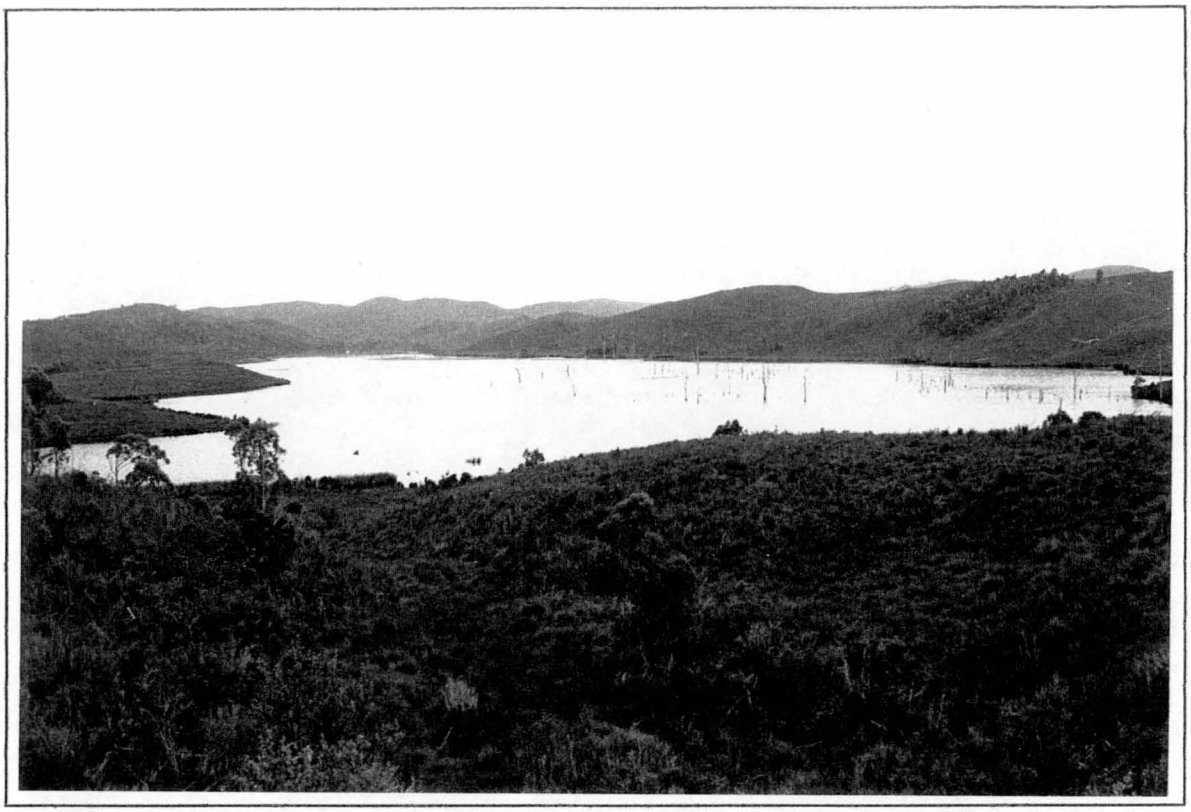


Plate 16. Parting Creek Dam. A man-made reservoir showing inundated *Eucalyptus* scrub.

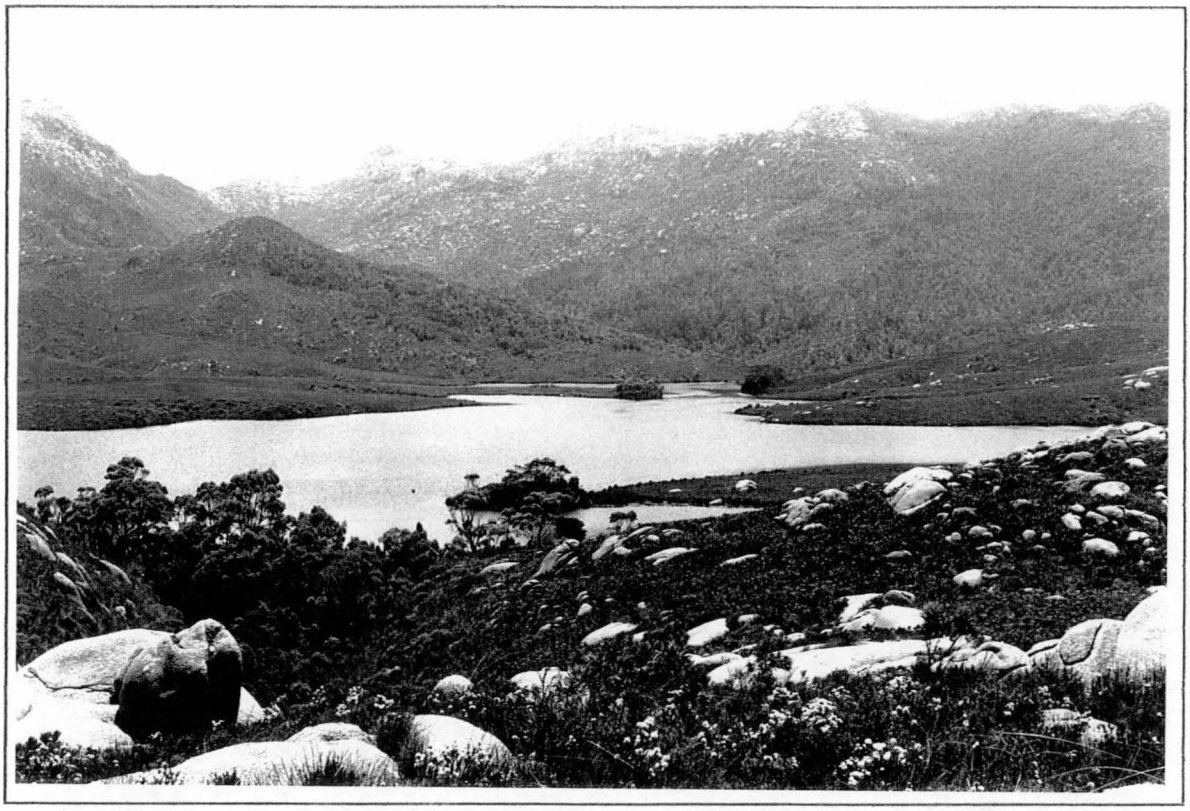


Plate 17. Lake Cumberland. Small artificial lake with Mt. Cumberland shown in the background.

Site	Zmax(m)	Surface area (ha)	Description	Lake Type
Hibbs Lagoon	8.00	*	River valley and siliceous sands	Natural impoundment
Lake Bantic	7.50	*	Holocene parabolic/longitudinal dune on siliceous sands	Perched lagoon (type i)
Lake Garcia	9.50	*	Holocene parabolic/longitudinal dune on siliceous sands	Perched lagoon (type i)
Lake Koonya	4.50	002.00	Tertiary sediments and Holocene siliceous dunes	Slope change
Lake Mallana	4.50	001.00	Tertiary sediments and Holocene siliceous dunes	Dune contact (type iv)
Lake Cumberland	4.00	*	Reservoir	reservoir
Lake Strahan	2.50	003.00	Holocene parabolic/longitudinal dune on siliceous sands	Perched lagoon (type i)
New Lagoon	<1.0	001.00	Holocene parabolic/longitudinal dune on siliceous sands	Perched lagoon (type i)
Parting Creek Dam	5.50	*	Reservoir	reservoir
South Strahan No. 1	1.50	002.00	Holocene parabolic/longitudinal dune on siliceous sands	Perched lagoon (type i)
South Strahan No. 2	1.50	001.00	Holocene parabolic/longitudinal dune on siliceous sands	Perched lagoon (type i)

Table 7.1 West Coast site morphometry and site description

hydro electrical plant. The lake is at 450 m elevation yet only 2.5 kilometers from the coast (**Plate** 17).

The physicochemical and limnological properties of the natuural lagoons have been investigated by a number of authors, and their unique or restricted algal flora has been reviewed (Bowling *et al.* 1993; Koste & Shiel 1986, 1987; Shiel *et al.* 1989; Timms 1987; Tyler 1996).

7.5 METHODS

Physicochemical and biological samples were collected approximately at three to five month intervals between August 1991 and November 1994 from nine lagoons and two man-made lakes between the mouth of Macquarie Harbour and Trial Harbour, and south of Macquarie Harbour at Point Hibbs. This broad scale approach was mainly to provide an indication of the variation among the lagoons, covering a range of lagoon types over the study area. A detailed description of methods used is given in Chapter 2.

The two man-made lakes, L. Cumberland and Parting Creek Dam, were investigated to give some comparison with the natural lagoons to see if mode of origin of the water body had an influence on limnological conditions and in turn on the microcrustacean fauna.

Morphometric characteristics of the lagoons were obtained from field observations, aerial photographs and 1:25,000 topographical maps using a Tamaya Planix 7 planimeter. Maximum depth (Z_{max}) was measured by use of a graduated line and depth measured every 0.5 m interval with a plumbline and hand held depth sounder from a small inflatable dinghy. Bathymetric maps of several of the lagoons were drawn using the methods outlined in Chapter 2. Geomorphological analyses of the lagoons was based on aerial photographs, topographical maps, ground photographs and field investigations

7 6 RESULTS.

7.6.1 Morphometry

The lagoons of the West coast (**Table** 7.1) tend to be deep relative to surface area in contrast to coastal lagoons in other Tasmanian regions and the Bass Strait Islands (**Figure** 7.3-7.5). L. Strahan (**Figure** 7.6) experiences a moderate degree of astaticity, particularly in the north-western corner of the lagoon with the exposure of an extensive, flat shoreline. Only the shallow South Strahan Lagoons (**Figure** 7.6) and New Lagoon could be described as seasonal, markedly fluctuating in surface area and volume as they are augmented by rainfall or as they contract by evaporation . All the natural lagoons have a very limited catchment area consisting of the lagoon surface area plus an immediate bordering area. Of the natural lagoons only Hibbs Lagoon, L. Mallana and L. Koonya have well defined inflow or outflow creeks.

7 6 2 Physicochemical Parameters

Limnological conditions are summarised in **Appendix** 13. The moderate depth of many of the lagoons, the surface area relative to Z_{max}, and light summer winds coupled with high summer temperatures highlight the possibility of thermal stratification. L. Bantic and L Garcia have in the past shown thermal stratification (Croome & Tyler 1988; Bowling *et al.* 1993) L. Mallana, L. Cumberland and Parting Creek are of sufficient depth that thermal stratification may also occur. L. Mallana in particular is rather deep relative to surface area and it is thought that stratification would

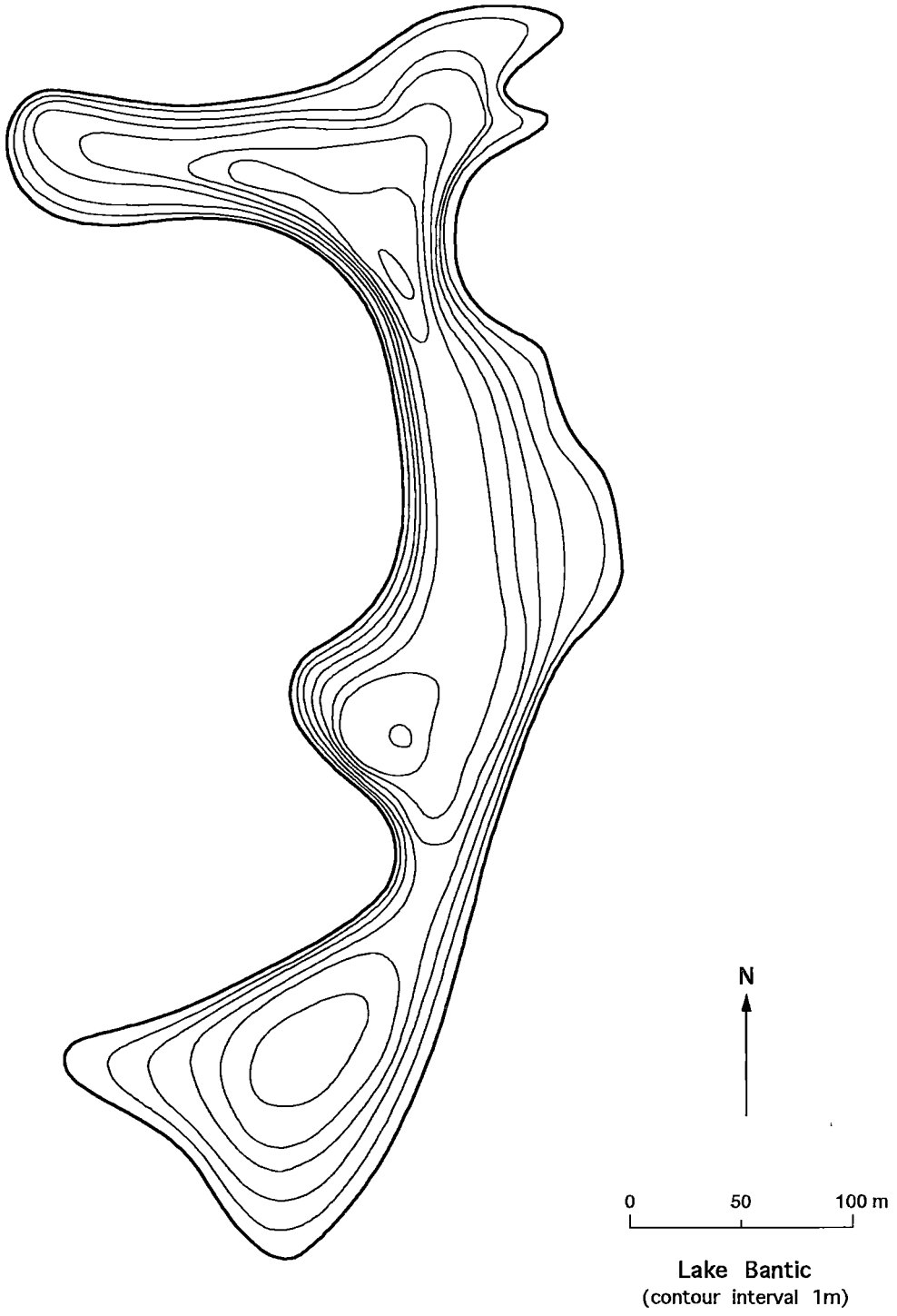


Figure 7.3 Bathymetry of L. Bantic. A dune lake on the West Coast of Tasmania

Figure 7.4 Bathymetric map of L. Garcia. West Coast of Tasmania.

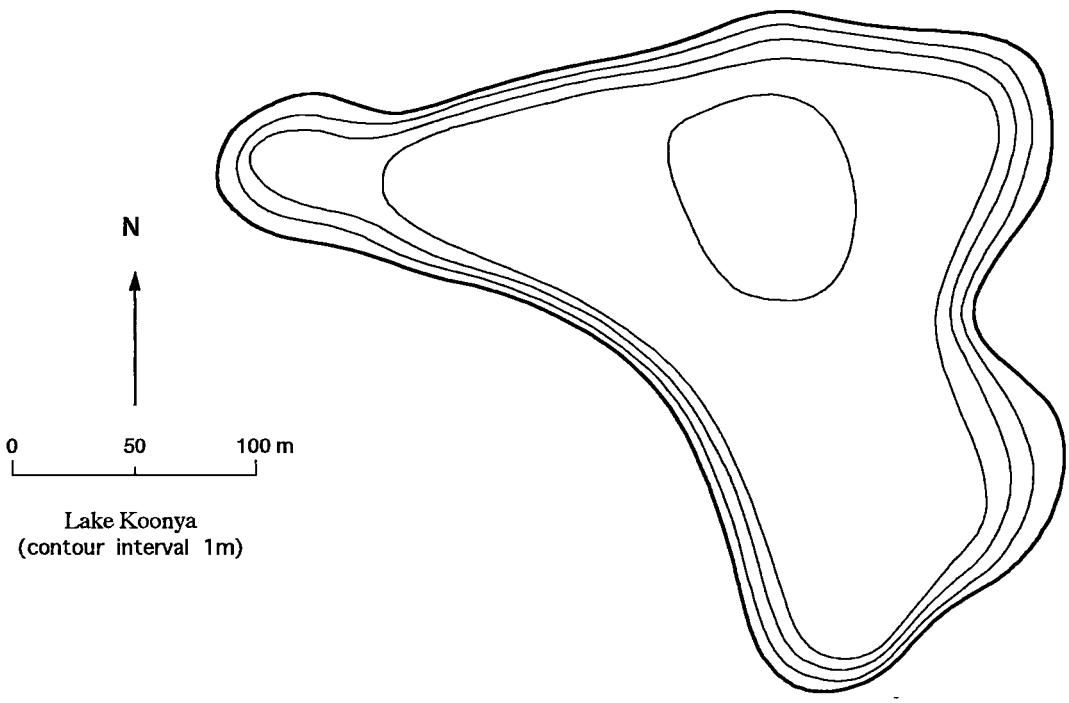


Figure 7.5 Bathymetric map of L. Koonya. West Coast of Tasmania

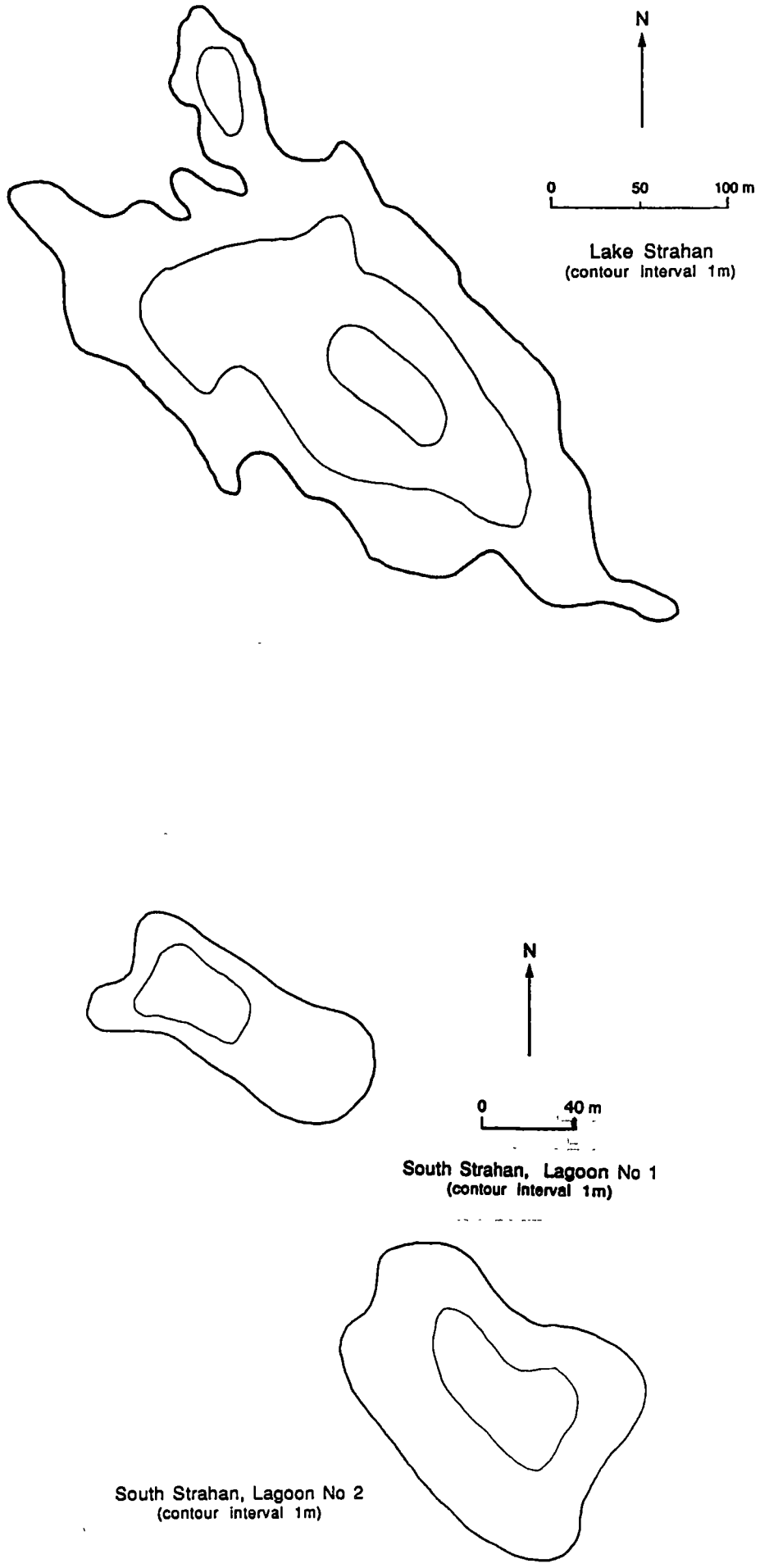


Figure 7.6. Bathymetry of Lake Strahan and the South Strahan Lagoons. West Coast of Tasmania.

occur most readily in this lagoon. In contrast, the remainder of the lagoons are thought to be too shallow (less than 1 5-2.0 m depth when full) to allow a thermal gradient to develop. Polymixis in shallow lagoons has been recorded, though warm still days and cold windless nights have allowed transient thermal gradients to develop.

Lake Bantic (2/2/93) and Lake Garcia (2/4/92 & 8/11/94) show thermal straification of the water column (**Figure** 7.7). L. Garcia (17/5/94 & 16/6/94) possessed a physicochemical profile suggesting that autumn turn over of the dune lake had occurred with the water column now isothermal. The sharp and drastic increase in K_{25} in the bottom waters, at the sediment water interface of L Garcia and L. Bantic is attributed to increased ionic conductivity of interstitial waters of the lake sediments. Similarly the sharp drop in DO_2 in L. Bantic (16/6/92) is attributed to anoxic interstitial waters of the sediments rather than stratification of the water column.

Physicochemical conditions in Lake Garcia (4/2/93) (**Figure** 7 8) are similar to those recorded in L.Chisholm (Bowling & Tyler 1988, Croome & Tyler 1988) Although the changes in total ionic concentrations across the thermocline were not great there was considerable physicochemical structure in the water column. The 4^{o} C drop in temperature between 1 0 m and 2.0 m is indicative of a stratified lake. The DO_2 profile shows a significant drop in DO_2 just below the position of the thermocline (1-2 m), followed by an increase in DO_2 content from 2.3 m to 5.0 m. This "bulge" was followed by a general decline in DO_2 content to the sediment, although bottom waters were still oxic, but at low concentrations.

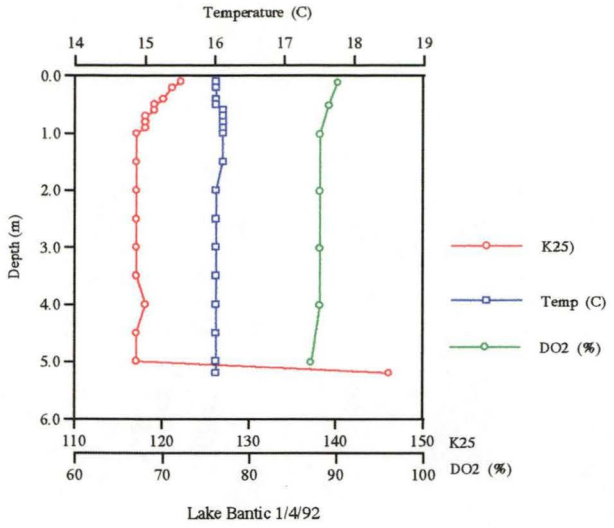
Parting Creek Dam (8/10/91) physicochemical conditions showed a 2^{o} C rise in water temperature within the first 0.5 m increase in depth (**Figure** 7.9). From this depth to the sediment the water column was iothermal. This profile is attributed to the loss of heat from the surface waters during the preceeding still, bitterly cold night, and is not taken to indicate a stratified lake The lake has a relatively large fetch and is not thought to stratify.

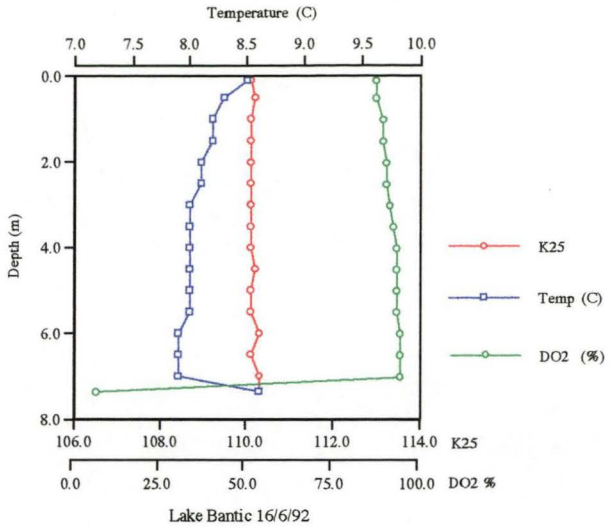
The conductivities of all lagoons were low with most <250 μScm^{-1} (K_{25}), the exception being L. Strahan which on a single occasion had a conductivity of 1364 μScm^{-1} This is believed to be a contaminated sample or the result from the use of an unequilibrated meter. The two South Strahan Lagoons, in contrast, consistently had higher conductivities than the other lagoons and are considered to be of moderate conductivity. There appeared to be relatively little temporal variation within the respective lagoons.

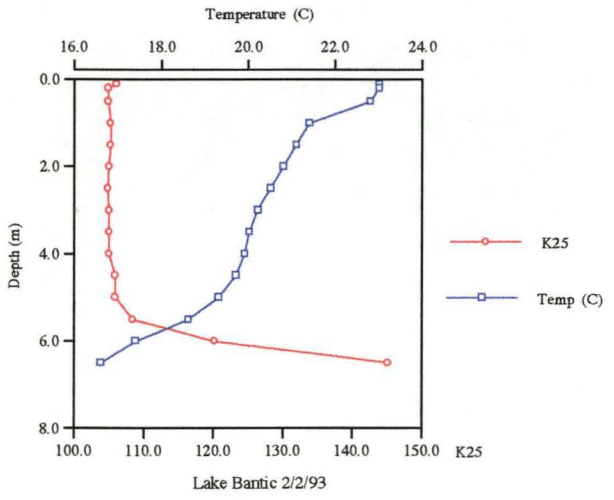
The g_{440} values of the lagoons sampled were indicative of moderate to ultra-dystrophy. Bowling *et al.* (1986) classified lakes with g_{440} values <1.0 m^{-1} as clear waters and on this criterion only L. Bantic would be regarded as non-dystrophic. Most are moderately to highly dystrophic with g_{440} values between 5.0-25.0 m^{-1} . The two South Strahan lagoons were, on all occasions sampled, ultra-dystrophic and "blackwater". L Strahan displayed the greatest relative variation in dystrophy. The other West Coast lagoons were, in contrast, relatively stable and temporal variation in colour was insufficient to change the respective lagoons' classifications.

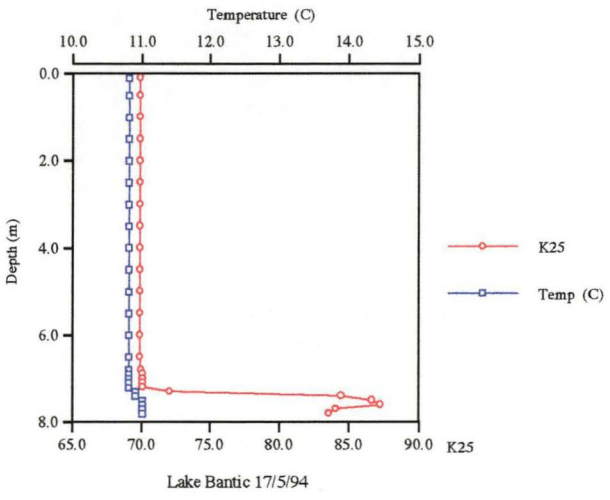
As expected from the dystrophic nature of these lagoons, pH values were usually less than 5 0 L. Koonya, L. Mallana and the South Strahan lagoons were extremely acidic with pH values usually below 4.0. Parting Creek displayed the greatest temporal variation of the lagoons with a pH range of 4.5-5.95.

Turbidity of all lagoons was low. Those values that were recorded are attributed to suspended fine particulate organic material derived mainly from peaty soils and with decomposition retarded by









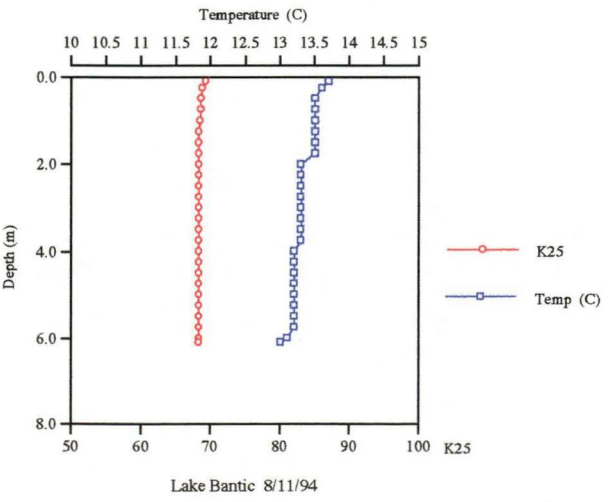
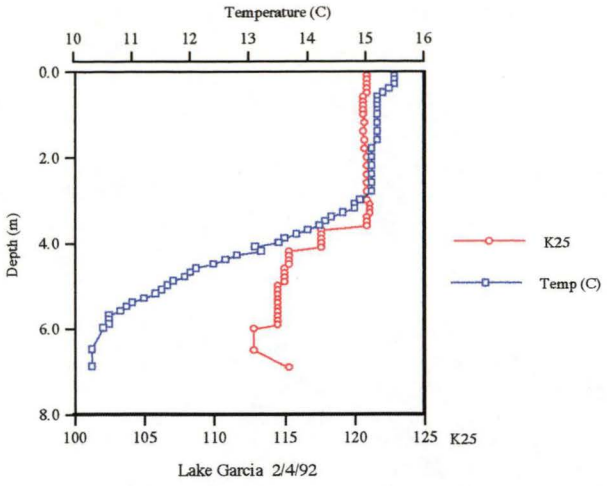
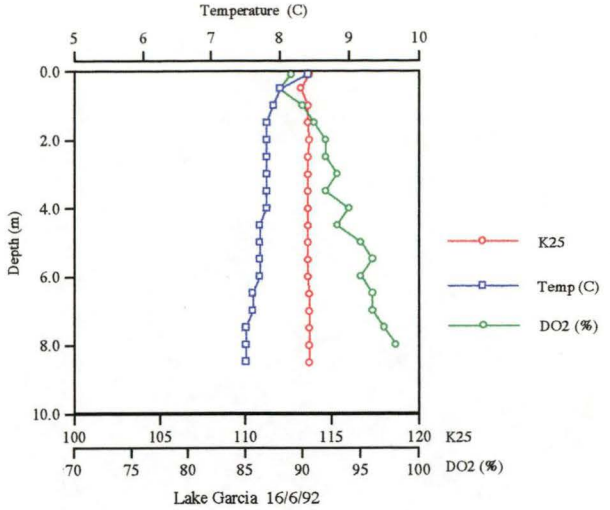
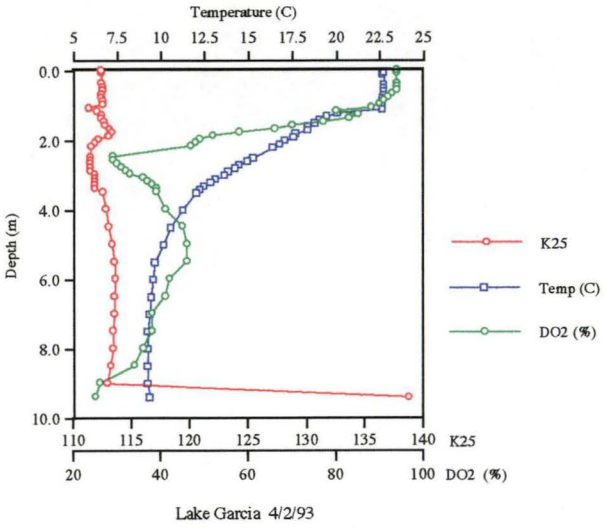
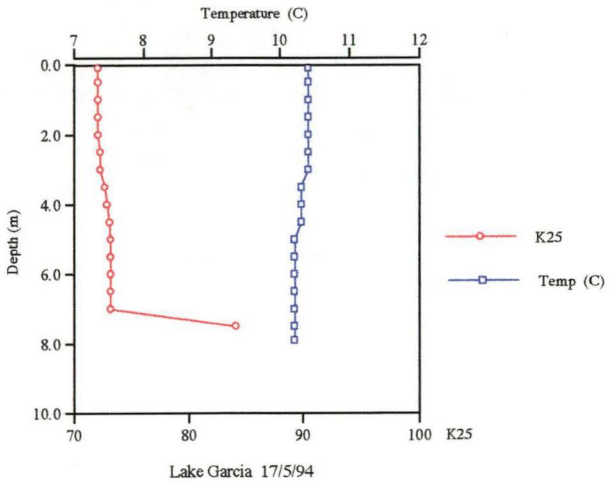


Figure 7.7 L. Bantic physicochemical profiles









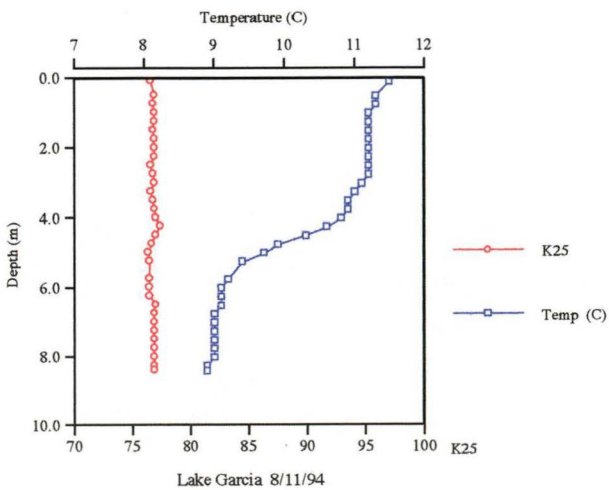
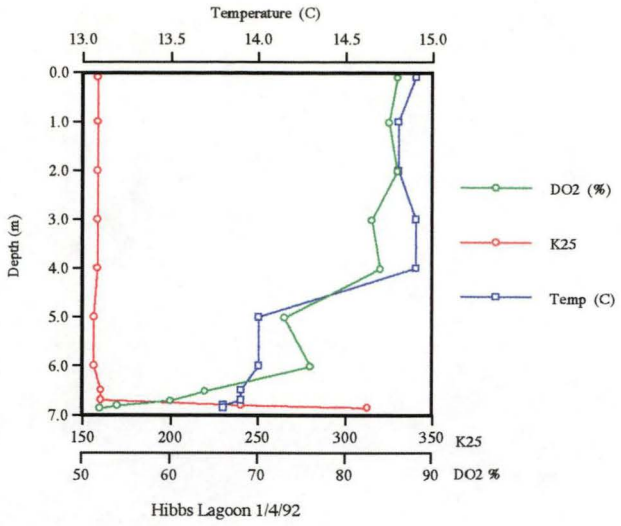
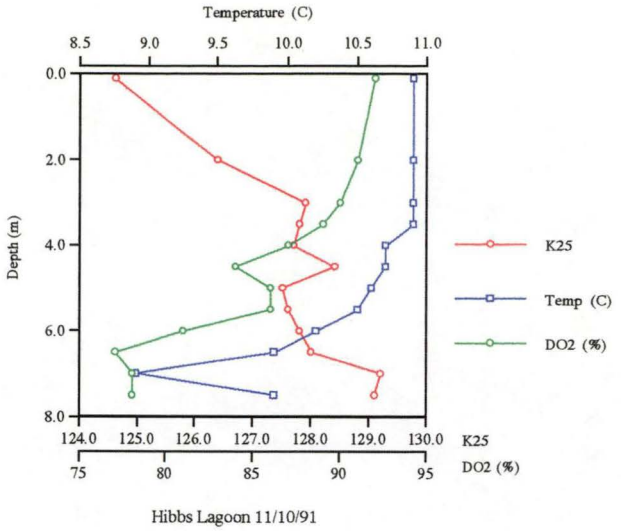


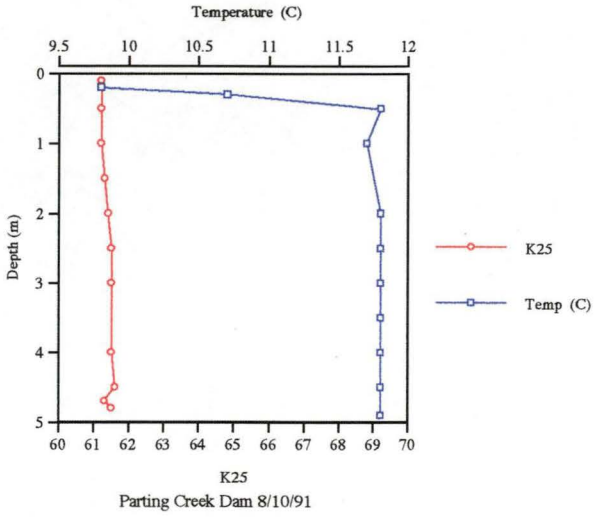
Figure 7.8 L.Garcia physicochemical profiles.



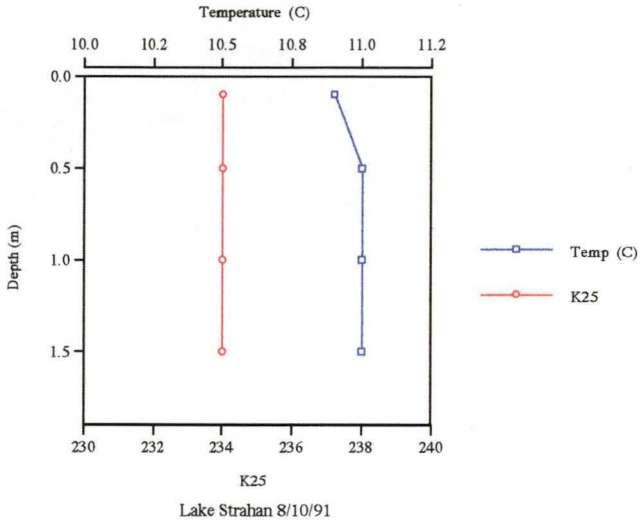
Hibbs Lagoon 1/4/92



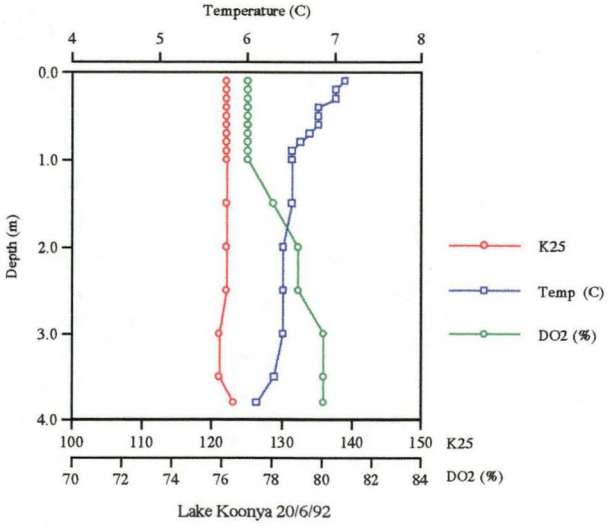
Hibbs Lagoon 11/10/91



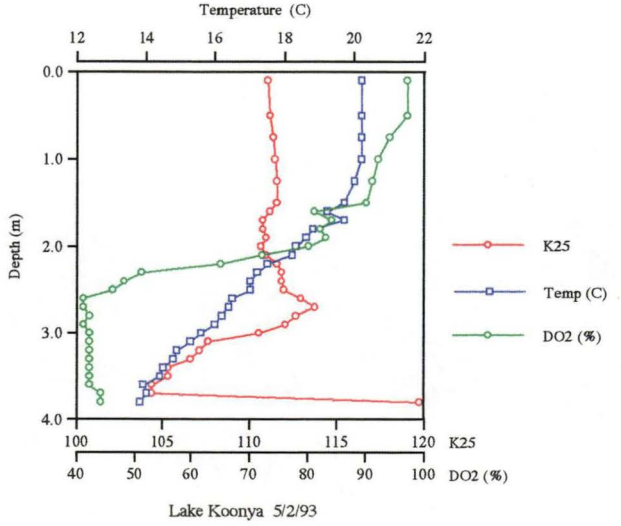
Parting Creek Dam 8/10/91



Lake Strahan 8/10/91



Lake Koonya 20/6/92



Lake Koonya 5/2/93

Figure 7.9 West Coast lagoons physicochemical profiles.

the acid conditions within the lagoons.

Na and Cl are the major ions in all of the lagoons most of which had a seawater order of ionic proportions. Exceptions were L. Garcia on one occasion with a cation order of Na>Ca>Mg>K, and L. Cumberland, L. Mallana and and L Strahan on one occasion each with the ionic order Na>Mg>K>Ca. Faulty analysis is suspected for these occasions. L. Garcia displayed an anionic order of $Cl>HCO_3>SO_4$ as did L. Bantic, L. Mallana, L. Strahan and Parting Creek on one sampling occasion. In the majority of cases the enrichment by bicarbonate is accompanied by a rise in pH (>5.0).

7.6.3 Biological Features.

A number of lagoons have emergent stands of *Eleocharis sphacelata* fringing their shorelines or growing from other shallow areas. *Triglochin procera* is common in some lagoons, notably L. Garcia, Hibbs Lagoon, L. Strahan, and L. Mallana. The latter two lagoons were fringed by caespitose stands of *Restio tetraphyllus, Baumea* sp , *Chorisandra* sp., and also by *Sphagnum* spp. *Chara* was growing on the bottom of L. Bantic Generally the aquatic macrophyte community was restricted to a very narrow band around the littoral fringe of most of the lagoons

Appendix 14 lists the microcrustacean species found in the West Coast lagoons. The list is by no means complete but yet is a good representation of the microcrustacean species found there. Typically the true microcrustacean zooplankton community was monospecific consisting of *Calamoecia tasmanica tasmanica.* The exceptions were L. Bantic and L Garcia where *Ceriodaphnia sp.* was recorded in large numbers but subdominant to *C. tasmanica* In L. Cumberland the only planktonic species was *Bosmina meridionalis. B. meridionalis* also occurred in Parting Creek as a subdominant to *C. tasmanica* It was of interest that this species was only recordedfrom the two artificial water bodies. *Daphnia* was recorded only once, in L Mallana Chydorid species were either associated with the littoral macrophyte community or benthic community with the total number of species varying from two to four Most belonged to *Alona* spp., *Alonella* sp. or *Chydorus* spp.. *Ilyocryptus* and *Scapholeberis* were found in those lagoons with a fringing emergent aquatic macrophyte community In contrast *Pseudomoina lemnae* was most common in the more shallow lagoons experiencing some astaticity and where the emergent macrophyte community was restricted to the central areas of the lagoon. The relatively flat shoreline is alternately exposed and inundated as water levels in these lagoons fluctuates

7.7 DISCUSSION.

7.7.1 Limnology.

The West Coast lagoons are relatively deeper and less exposed to strong onshore winds than the North East lagoons, thus thermal stratification is more likely in those with sufficient depth and shelter such as L.Garcia, L. Bantic and L Mallana (Bowling *et al.* 1993), although strong transient temperature gradients may be present in others during calm summer conditions, as is frequent in dystrophic lakes (Jones & Arvola 1984; Bowling & Salonen 1990).

The rapid attenuation of solar radiation characteristic of dystrophic lakes leads to a sharp shallow thermocline in Lake Garcia. The colour and relative shelter from wind encourages early stratification in spring and its perisistence until autumn. This is in contrast to the clear waters of L. Bantic. L. Bantic, not dystrophic like its near neighbour L. Garcia, does not stratify untill later in

the summer, the clear oligotrophic waters of this lake not attenuating incoming solar radiation to the degree as L. Garcia.

The shallow lakes were isothermal with bottom waters well oxygenated. The sharp drop in the DO_2 profile for L. Garcia (4/2/93) is attributed to the high biological O_2 demand of a thin plate of flagellates and/or zooplankton in the metalimnion/thermocline. It is also possible that the increase or "bulge" in the DO2 profile below the metalimnion/thermocline is attributed to the photsoynthetic activity of a plate of phytoflagellates. However this is thought not to be the case because of the low light levels at that depth. Microzonation by zooplankton is known from Tasmanian dystrophic waters. Copepod naupli and rotifers occur in the mixolimnion where they are concentrated in a narrow zone just above the oxic/anoxic interface (Miracle *et al.* 1991) In this instance the bottom waters of L. Garcia are still oxic and the zooplankton are thought to be concentrated in a narrow zone at the thermocline.

Polymixis is common for coastal lagoons in the North East of Tasmania and in other areas (Timms 1969; Bayly *et al.* 1975; Arthington *et al.* 1986; Outridge *et al.* 1989), though Bowling *et al.* (1993) make the point that in Tasmania some lagoons (-i.e. L. Garcia) may be warm monomictic if depth and shelter are adequate (Bensink & Burton 1975; Green 1975; Longmore *et al.* 1983; Kling 1986). As with Cape Portland No 3 on the North East Coastal plain, seawater may intrude periodically into Hibbs Lagoon. Compared to Cape Portland No 3, Hibbs Lagoon is deeper (7-8 m) so that it may be made meromictic for a period. In the case of Cape Portland No. 3 meromixis is not thought to occur as the lagoon is very exposed to strong onshore winds and is very shallow (<1.5 m) so that any seawater would soon be mixed throughout the overlying water column

The West Coast lagoons are considerably more dilute than those of the North East Coastal plain and also more so than their mainland counterparts. The water chemistry of the West Coast lagoons is predominantly one of low salinity, moderate to high dystrophy, low pH and a seawater ionic order, as found by Bowling *et al.* (1993) These features dominate the limnology of western Tasmania, both coastal and inland, determined by the inertness of the underlying Pre-Cambrian rocks and by a mantle of peat forming vegetation yielding organic acids (Buckney & Tyler 1973a, b). The chemistry of the Bruny Is. lagoons (Walsh *et al.*, in press) and coastal lagoons on the East Coast is similar (Bowling *et al* 1993). Coastal lagoons on the North East coastal plain (Chapter 3) show higher proportions of calcium and bicarbonate than is usual for western lagoon waters along with higher pH's. This is attributed to the more calcareous nature of the Holocene dunes there in comparison to the relatively more siliceous Pleistocene dunes of the west coast.

The limited seasonal coverage of the West Coast lagoons confirms the opinion of Bowling *et al.* (1993), for the West Coast at least, that though there is some variation in water chemistry it is insufficient to change the general limnological character of the lagoons. i.e. the West Coast lagoons are stable in relation to their physicochemical environment. This has implications for the general microcrustacean spatial habitat heterogeneity, ecology and diversity.

7.7.2 Biology

Microcrustacean species diversity was very low for the western lagoons. Only one species of calanoid copepod, *C. tasmanica tasmanica*, was present in these lagoons, though Walsh (1991) also recorded *Calamoecia australis* from L Garcia and *Gladioferens spinosus* from Hibbs Lagoon

Cladoceran faunal diversity was also correspondingly low, consisting mainly of chydorids. *Ceriodaphnia* was common in L. Bantic and L. Garcia where it was codominant or subdominant to *C. tasmanica tasmanica*. *Bosmina meridionalis* was dominant in Lake Cumberland and also planktonic in character.

Noted was the absence of ostrocods and harpacticoids from the West Coast lagoons. This may be attributed to the paucity and low diversity of shallow littoral macrophytes and acidity of the lagoons. Though present in most samples, there were relatively few cyclopoids. Cyclopoids (and harpacticoids) in mainland Australian waters appear to prefer epibenthic or epiphytic niches; their scarcity or absence from the western lagoons may be a sampling bias towards planktonic collections but this is unlikely. Hammond (1987) did not record any harpacticoid species from the West Coast and from only two sites in the North West. It is also possible that with a more vigorous and frequent sampling regime of the narrow littoral fringe of the West Coast lagoons the microcrustacean species list recorded from these lagoons will be expanded.

A possible explanation of low species diversity may be the simple aquatic macrophyte community found in the narrow littoral fringe of these lagoons. Typically this community consists of a narrow band of *Triglochin procera* or *Eleocharis sphacelata*. These plants morphologically are straight, unbranched stemmed and vertical, though the fronds of *Triglochin procera* may float on the surface. The low diversity in aquatic plants of differing morphology would provide a corresponding low range in niche diveristy for the littoral cladoceran fauna

A further mechanism to explain low species diversity is that the West Coast lagoons are stable habitats. The lagoons have a very narrow littoral fringe, are deep and relatively small in surface area and rainfall is year round. Therefore seasonal fluctuations in the hydrology of these lagoons do not affect their ecology to the same degree as the NE lagoons - i.e. a small change in depth is not associated with a large change in surface area and volume, with a concomittant change in the physical and physicochemical environment This instability would facilitate the opening and closing of differing niches and spatial habitat heterogeneity.

7.8 CONCLUSION

Site species paucity of the microcrustacean fauna is in marked contrast to the rich assemblage of rotifer fauna (Koste *et al.* 1988) and that of the microflora (Bowling *et al.* 1993; Tyler 1996), and is in contrast to that recorded for the dune lakes of NE Tasmania. The above named calanoid copepod species are all planktonic, whereas the diverse cladoceran fauna of the NE coastal plain generally live at the sediment water interface, burrow in the sediment floc or climb on emergent vegetation, i.e. they are littoral or epibenthic in habit or prefer shallow open vegetated waters. The lagoons of the West Coast have relatively large areas of open deep water, lack a well defined littoral zone, have relatively simple macrophyte communities, are deep relative to surface area and have stable waterlevels and relatively definite shorelines The high rainfall of the region ensures even shallow lagoons usually contain water Therefore niche diversity, and as a consequence species diversity, is low.

CHAPTER 8

LIMNOLOGY OF BRUNY IS LAGOONS WITH REFERENCE TO THE MICROCRUSTACEA (IN PARTICULAR *BOECKELLA NYORAENSIS*)

8.1 ABSTRACT

The Bruny Island lagoons house the rare copepod *Boeckella nyoraensis*. This copepod favours shallow, ephemeral waters of variable high to extreme dystrophy The Bruny Island lagoons are rich sites for other microcrustacean species and are significant lagoons, similar to those in the South West World Heritage Area, and Fraser and Morton Islands They are located in close proximity to the sea and are on a siliceous substratum which contributes little in the way of ions by weathering.

8.2 INTRODUCTION

The occurrence of an extremely rare invertebrate that dominated the zooplankton assemblage in lagoons of Bruny Island is noted (Baharuddin 1978; Walsh 1991). The animal, *Boeckella nyoraensis* Searle (Copepoda:Calanoida) is described in Bayly (1964b, 1979). The organism is endemic to Australia and has been recorded only sparsely (Bayly 1979)

It is a rare species first found in 1912 by Searle (Bayly 1964b) in Nyora near Westernport (Victoria) and since recorded only in a coastal lagoon on the south eastern Australian mainland (Timms 1977) and from D'Arcy's lagoon (Bruny Is) by Baharrudin (1978). However in a recent taxonomic survey of the calanoid copepod fauna of Tasmania, Walsh (1991) recorded this species from four of five sites investigated on Bruny Island. Identification was verified by Dr. I. A. E. Bayly (Monash Uni. pers. comm.).

The aims of this particular study were to compare limnologically, the lagoons of the North East and the West Coast with Bruny Island, to give some insight into the ecology of *Boeckella nyoraensis*.

8.3 STUDY SITES

Bruny Is. is an elongated landmass, lying north-south, separated from the Tasmanian mainland by a narrow stretch of coastal waters occupying the drowned former course of the Derwent River. Bruny Is. is in essence two separate islands connected by a tombola produced by longshore drift forming a long narrow spit of siliceous dunes, within which are found a series of coastal lagoons (**Figure** 8.1).

The dune system of the isthmus is poorly developed consisting of little more than a frontal dune beach ridge system. To the north of the isthmus this system branches with Adventure Bay possessing a single high foredune forming one limb of a bisected dune beach ridge system. The other limb is formed by the northernmost beach of Isthmus Bay. Adventure Bay has a well developed dune system to the north of the isthmus behind the frontal dune system whereas the isthmus is poorly developed. These ridges and the two arms of the foredune system form a barricade to a lagoon-marsh complex (**Plate** 18).

The vegetation ranges from colonising grasses on the dunes, through low *Banksia* dominated shrub to small pockets of mature *Eucalyptus* and *Melaleuca* in the swales. The area around Big Lagoon is predominantly heath Adjacent Cape Queen Elizabeth, forming part of the catchment, is mainly grassland and herbfields.

Almost all of the dominant species of aquatic plants were emergents. Most of these lagoons have extensive emergent stands of *Triglochin procera* R Br (Juncagenaceae), notably D'arcys Lagoon. Bains Lagoon and Big Lagoon have such stands fringing their shorelines or growing from shallow areas (**Plate** 19).

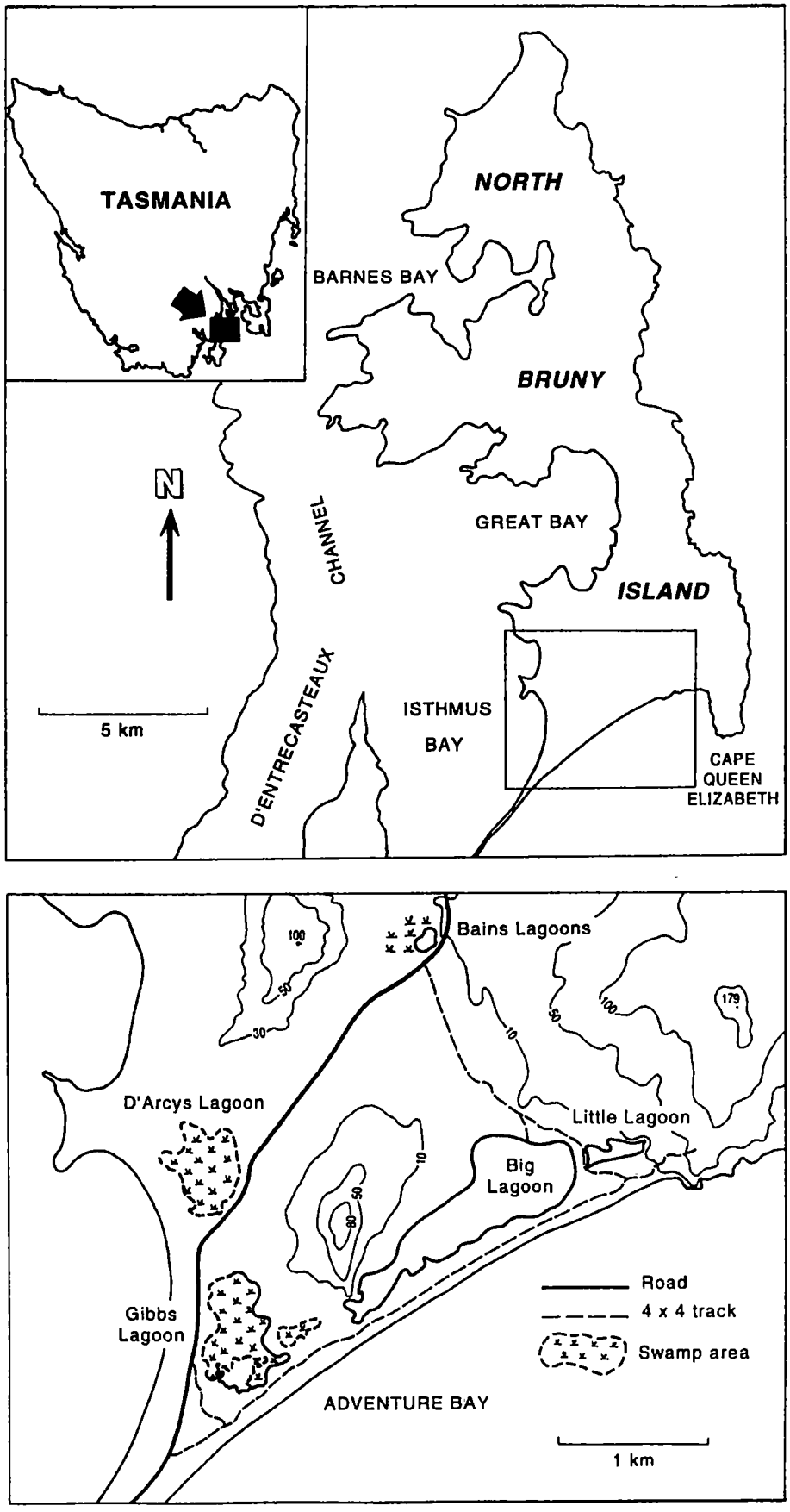


Figure 8.1 Maps showing location of Bruny Island and the lagoons at the "neck".

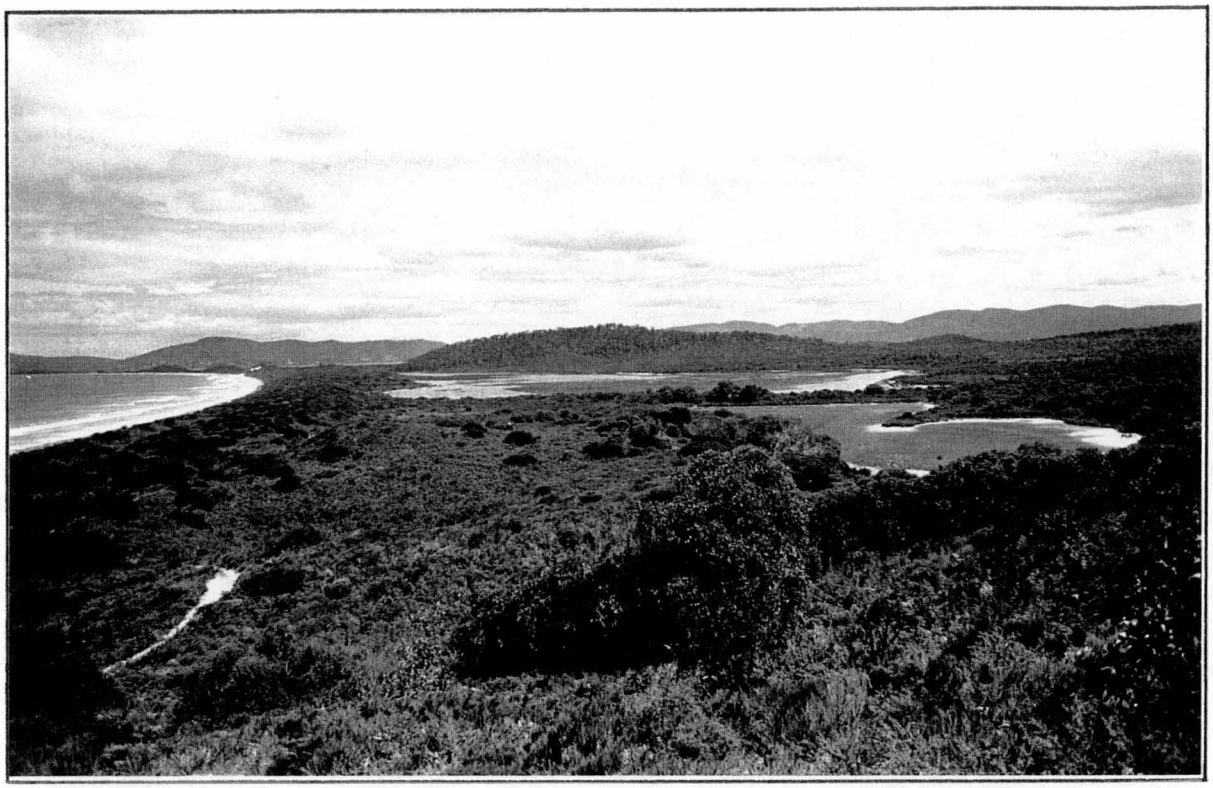


Plate 18. Looking south-west along Adventure bay beach. Big Lagoon (Plate 19) centre; "the neck", left centre; Little Lagoon, right fore ground.

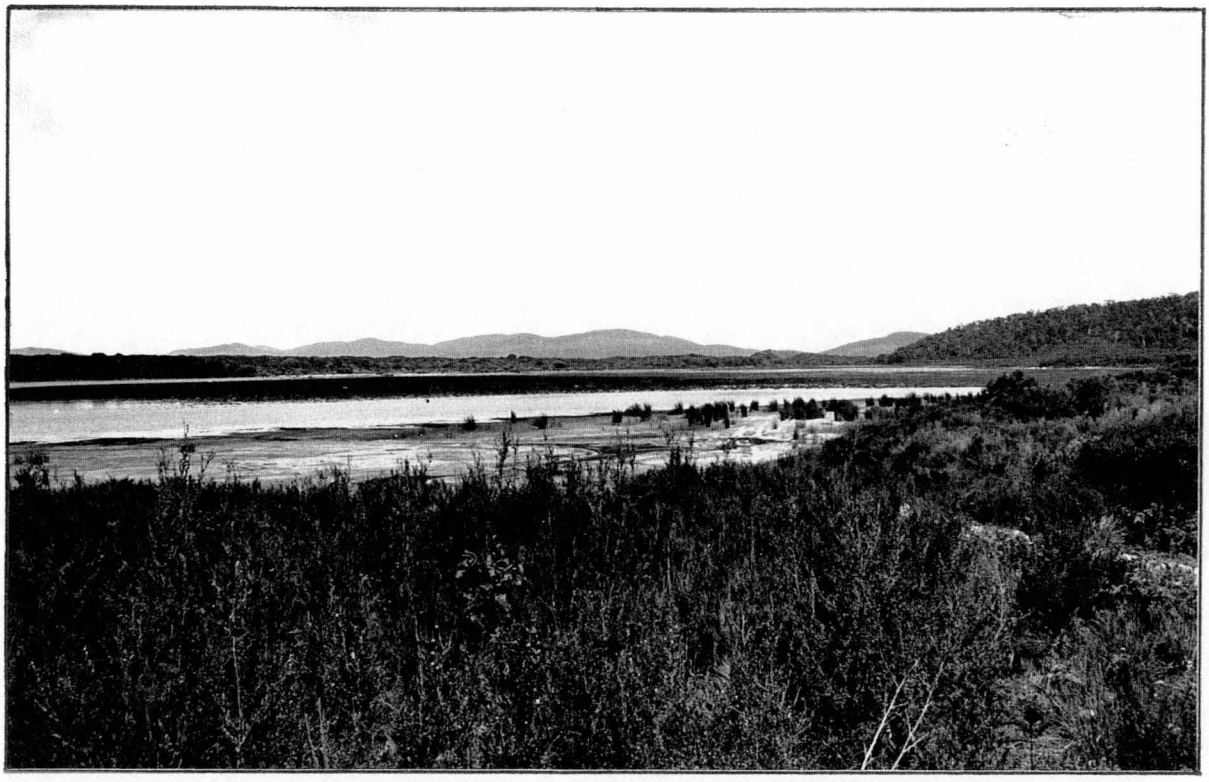


Plate 19. Big lagoon, Bruny island, looking south-east from the northern end of lagoon.

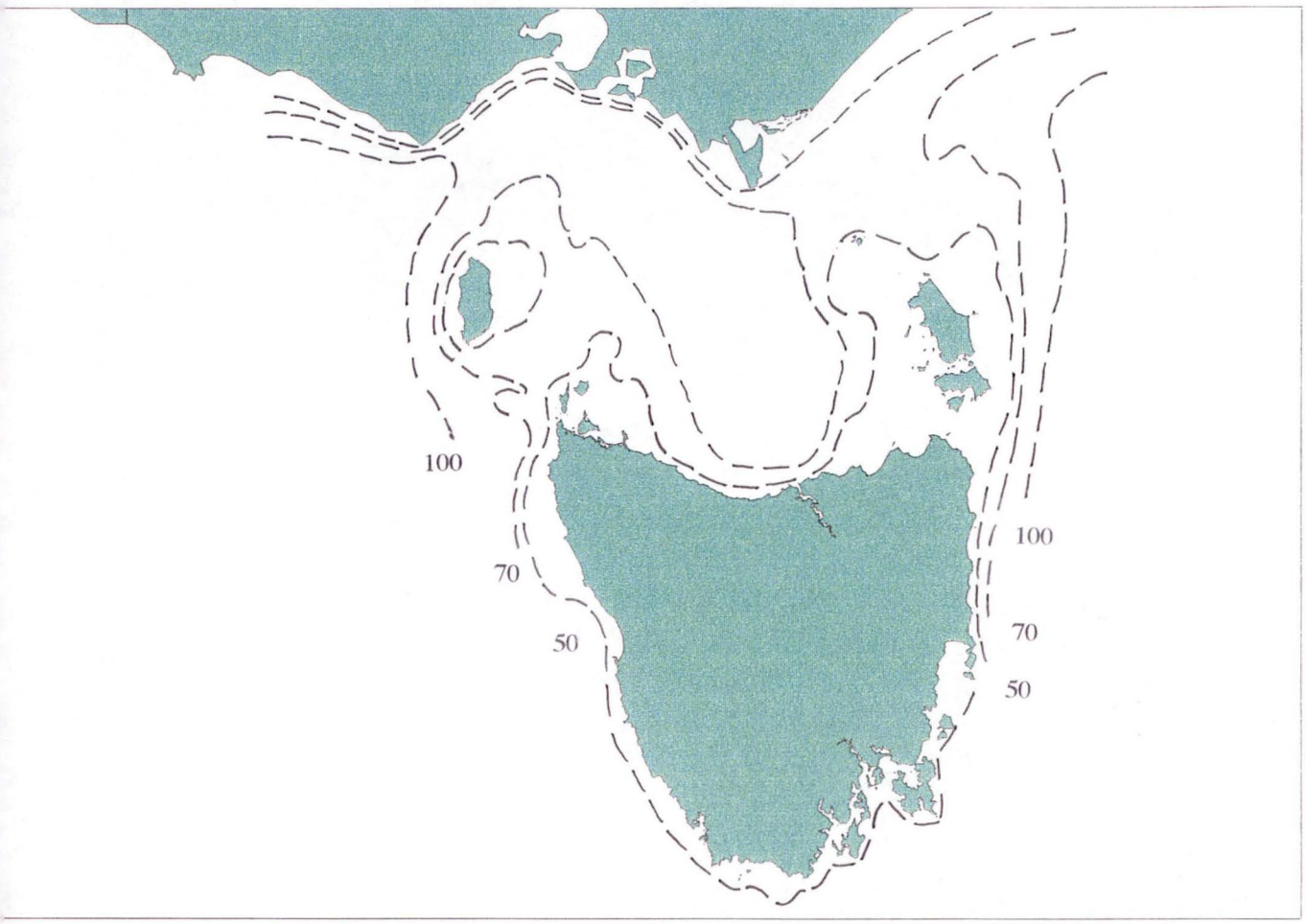


Figure 9.1. Coastline of Tasmania during the Last Glacial. The 100m isobath approximates the maximum lowering of sea level during the height of the Last Glacial. The area within the 100m isobath formed a peninsular landbridge to mainland Australia.

Big Lagoon has an extensive flat low lying shoreline vegetated with *Baumea* sp., *Juncus pallidus* and *Potamogeton* sp , which is frequently inundated by a variable water level. Big Lagoon is the only site that contains water year round, and has an extensive emergent stand of *Triglochin procera* in deeper waters (**Plate** 19).

Little Lagoon, a shallow depression, is only 20 m from Big Lagoon and is separated by a small rise 2 m in height. Little Lagoon is 1 m higher in elevation than its larger neighbour. Little Lagoon is little more than a small sandy hollow with no aquatic macrophyte vegetation It is usual for this water body to contain water only during the winter season or following rain events in summer.

Gibbs Lagoon is ephemeral with caespitose stands of *Melaleuca* scrub emergent from the lagoon and with extensive fringes of *Juncus* and *Baumea.* Gibbs Lagoon is actually an extremely shallow series of small ephemeral lagoons, draining an extensive marshy area, that join together forming one body during winter. In summer, with a drop in the water level, a series of shallow open pools develop that may completely dry by summers' end. Like Big and Little Lagoons it is subjected to the vicissititudes of unthinking recreational enthusiasts.

Bains lagoon occupies a small hollow and is located within a corridor between old low lying dunes. This lagoon is the most disturbed, being all but destroyed by the construction of a road adjacent to it. Much of the lagoon has been filled by the road works. In addition much of the catchment has been cleared and converted to pasture. The lagoon is shallow and ephemeral with shrubby trees surrounding or covering the remnants of the waterbody. Bains Lagoon is choked with *Myriophillum simulans* and has areas of *Juncus pallidus, Villarsia reniformis* and *Isolepis fluitans* (Potamogetonaceae) Much of the surrounding littoral macrophyte vegetation shows evidence of disturbance by livestock.

D'Arcys lagoon is second in size to Big Lagoon It differs markedly from the latter in being ephemeral in particularly dry years, occupying a large low lying shallow basin with no to little open water when inundated and is completely covered with *Triglochin procera, Lepidosperma longitudinale, Juncus articulatus* (Juncaceae) and *Juncus procerus* (Juncaceae). In dry years it resembles little more than a reedy hollow. Like Bains lagoon it is subject to agricultural disturbance by livestock, but more importantly, its major drainage inlet has been dammed to provide a livestock watering hole, depriving the lagoon of a major water source. There is also the potential for destruction of the extensive macrophyte beds by livestock in dry phases of the lagoon, in addition to possible eutrophication Damage occurs by selective grazing and trampling of the macrophyte vegetation and also the introduction of exotic species in the outer parts of the littoral fringe. Unlike native marsupials, the hard hooved introduced grazers heavily disturb the ground surface and sediments of the shallows, increasing water turbidity, and aiding in the the spread of exotic macrophyte species many of which are opportunistic colonisers. *Triglochin procera* is one dominant species that is often temporarily eliminated to the depth to which cattle are capable of grazing (Kirkpatrick & Harwood 1983). Fire may also eliminate the littoral macrophyte vegetation when the lagoons dry, at least in the short term. Nothing is really known of the effects this would have on the resting stages of the aquatic microfauna.

8.4 METHODOLOGY

The lagoons were visited several times during the period 1988-1992. Unpublished information

for 1977 was obtained from Baharudin (1978). Additional information is used from Bowling *et al.* (1993).

8.4.1 Biological Collections

Zooplankton samples were collected by single or several oblique tows by hand held 20μm or 200μm conical plankton nets in Big Lagoon. All other lakes sampled were too shallow to conduct plankton tows. Instead samples were obtained by hand held plankton nets passed through the shallows. All collections were preserved in 5-10% formalin, pending identification. Nets were washed thoroughly before and after the sampling of each site in an effort to reduce the possibility of contaminants in the samples obtained.

Identification of the cladocera and copepods, and disarticulation methodology is discussed in greater detail in Chapter 2.

8.4.2 Physicochemical Collections

Water samples were collected in opaque plastic bottle in open water from the littoral fringes of each lagoon at 20-20 cm depth. Methodology used in physicochemical measurements is listed in Chapter 2.

8.5 RESULTS

8.5.1 Morphometric

All the sites were shallow, astatic, dystrophic, coastal lagoons, close to sea level and occupy deflation hollows located in siliceous dunes. The study sites differ physiognomically (**Table** 8.1) ranging from large relatively exposed lakes to small ephemeral ponds, from depths of 2 m to <0.5 m, from open water bodies to those dominated and covered by emergent macrophytes. Geomorphic and physiognomic data was obtained from topographic 1:25,000 maps of the island and from on site observations.

Table 8.1 Physiognomic features of sites studied.

Site	Type	Environs	Area (ha)	Z max (m)
Big Lagoon	lake	sandy lowland between frontal & inland dunes	57.8	2.0
Little Lagoon	pond	sandy deflation hollow	3 1	<1 0
Gibbs Lagoons	swamp	sandy lowland between frontal dunes	54 0	<0 5
Bains Lagoon	swamp	lowland between inland dunes	1.4	<0 5
D'arcys Lagoon	swamp	vegetated lowland behind frontal dunes	17.5	1 0

8.5.2 Physicochemical

Lagoon Sediments: In situ observations on exposed bottom sediments during dry phases of Gibb's and D'Arcys lagoons, indicated both possessed a high organic matter content, resembling dark organic ooze. This is attributed to the extensive and intense macrophyte cover contributing a high amount of autochthanous plant material to the surface sediments. Sediments in Big and Little Lagoons had lower amounts of organic matter and were noticeably lighter in colour and sandier in

texture. Little Lagoon was noticeably sandier than its close neighbour Big Lagoon. In Big Lagoon, areas of moderate depth (>1 m) were sandier than and had less organic matter than shallower, more frequently exposed areas on the western and southern fringes of the lake The differences in Big Lagoon are attributed to the lack of aquatic macrophytes away from the littoral fringe which would have contributed autochthanous organic matter to the surface sediments.

The lagoons were too shallow to measure the underwater light climate, but these may be inferred from g440 values and from comparisons with other non-turbid dystrophic waters The lagoons would have a predominately red underwater light climate with spectral distributions similar to many dystrophic Tasmanian lakes (Bowling *et al.* 1986).

The limited results indicate that there is some variation in water chemistry within the respective water bodies with temporal variation in water level. The total salt in solution and its concentration may vary greatly as water volume changes occur in these closed astatic lagoons (Cole 1968). This is evident in K_{25} values obtained for the lagoons (**Appendix** 15). Changes in relative ionic composition that accompany evaporation within basins have been described by Hutchinson (1957). Different ions precipitate out of solution at different rates as the lagoon dries via evaporation during the summer season (Williams 1987) - i e relative ionic proportions change as the lagoons dry -e.g. Gibbs Lagoon. However Bowling *et al.* (1993) believe such seasonal variation in Tasmanian coastal environments is insufficient to change the general limnological character of a lagoon. Nevertheless the results obtained indicate that such changes may occur particularly with regard to pH and degree of dystrophy (**Appendix** 15)..

The concentrations of major ions are given in **Appendix** 15. The order of cationic dominance in all lagoons was $Na^+>Mg^{2+}>Ca^{2+}>K^+$ and anionic dominance was $Cl^->SO_4^{2-}>HCO_3^-$ except Little Lagoon (23/12/92) where dominance was $Na^+>Ca^{2+}>Mg^{2+}>K^+$, and on one occasion Bains Lagoon (23/12/92) where $Na^+>Ca^{2+}>K^+>Mg^{2+}$. The $Na^+>Mg^{2+}>Ca^{2+}>K^+$ pattern of cationic dominance is common to coastal lakes elsewhere in Australia (Bayly 1964a, Bayly & Williams 1973; Bowling & Tyler 1984; Bowling *et al.* 1993; Timms 1973, 1982). Anionic dominance in Bains and Gibbs Lagoons respectively also displayed some temporal variation with $Cl^->HCO_3^->SO_4^{2-}$ and $SO_4^{2-}>Cl^->HCO_3^-$ recorded on one sampling occasion but not on others. This variation may reflect a seasonal difference depending upon time of year of sample collection.

pH values ranged from 4 42 to 7.9 with most circum-neutral. Gibbs Lagoon was acidic with little variation in pH and resembles the acidic and bicarbonate impoverished lakes of Fraser Island (Bayly 1964a). Big Lagoon, Bains Lagoon and D'Arcys Lagoon were all circum-neutral with the later two lagoons displaying some temporal variation. Little lagoon was the most alkaline These neutral levels are probably maintained by the moderate salinities with concomitant moderate concentrations of bicarbonate providing buffering even in the presence considerable amounts of gilvin. This phenomenon has been reported from other coastal lakes in Australia (Timms 1973, 1977) and also from the Bass Strait Islands (Bowling & Tyler 1984) and from Tasmania (Bowling *et al.* 1993).

8.6 DISCUSSION

8.6.1 General Discussion

Only Big Lagoon had open water deep enough to permit sampling for pelagic zooplankton. It

is interesting that this lake was found not to contain *B. nyoraensis*. In a study of the calanoid fauna of Tasmania (Walsh 1991), the large size of this species relative to all others recorded in the survey was immediately apparent. Cole (1966) in a study of calanoid copepods from permanent and temporary ponds found that cephalothorax lengths were greater in in the temporary ponds than in the permanent pond populations. Cole cites reasons for this as being either genetic and/or the result of superior food supply in temporary ponds. Humic compounds in dystrophic waters such as coastal lagoons may provide an energy source for the zooplankton (Prakash *et al.* 1975; Bayly 1964a, Salenon & Hammar 1986). It is noted that the humic content of these lagoons on Bruny Is. as measured by g440 are amongst the highest recorded for freshwater lakes. In addition, predation of large individuals by planktivores might select for the smaller individuals or species in permanent ponds (Brooks & Dodson 1965; Gardner 1981) This is put forward as a possible explanation for the absence from Big Lagoon which in the past has been stocked with trout. Trout, though not obligate planktivores and visual feeders, would readily remove a large brightly pigmented calanoid such as *Boeckella nyoraensis* (Hairston 1981; Byron 1982). The red colour is due to the presence of carotenoid pigments and its esters (Hairston 1976).

The conservation status of *B. nyoraensis* is inadequate. Horwitz (1990) lists the I.U.N category of this species as rare (R), yet nothing is known as to its life cycle, habitat requirements, biogeographical range and general ecology. This species is worthy of further investigation as to the above points. On the basis of the lack of information pertaining to this species and disturbance and threats to its current habitat locations, it is proposed that the I.U.C.N. category of this species be changed from rare (R) to unknown (K).

Table 8.2

Site	*B. nyoraensis*	status of site
Big lagoon	no	introduced salmonids, visited by fishermen, duck shooters and subject to recreational vehicles
Little Lagoon	yes	subject to recreational vehicle.
Gibbs Lagoons	yes	subject to recreational vehicles
D'arcys Lagoon	yes	subject to agriculture activity and drainage
Bains Lagoons	yes	almost destroyed by roadworks and agricultural activity

Water levels of these lagoons fluctuate considerably and as a result of these fluctuations shorelines are rather indefinite, dependent upon season and severity of the summer Such fluctuations are determined by rainfall-evaporation relationships and the internal seepage patterns of the lagoon basin and catchment.

It is the exposure of the littoral fringes and shallows of these astatic-ephemeral lagoons that allows most disturbance to occur with the enthusiastic incursion of recreational vehicles and the other agencies described (**Table** 8.2).

Of those sites in which *B. nyoraensis* is currently found, only one is in Crown Land game reserves, Little Lagoon. This lagoon is only some 70 m from the largest of the lagoons, yet its absence from Big Lagoon being attributed to the presence of introduced trout, coupled with the lack

of littoral macrophyte vegetation during periods of low water level which may provide a refuge for such organisms. Conversely it may be that *B. nyoraensis* requires periodic drying and reinundation of its habitat to complete its life cycle, explaining its presence in the ephemeral lagoons and not Big Lagoon

Besides housing the rare copepod, *B. nyoraensis*, the Bruny Island lagoons contained a number of unidentified amphipod, ostracod, cyclopoid and harpacticoid species found particularly amongst aquatic macrophyte weedbeds. *Biapertura* cf *setigera* was recorded from D'arcys Lagoon. *Alonella* sp. and *Chydorus* sp. from Big Lagoon. The calanoid copepod *C. australis* was also present in D'arcys Lagoon and Bains Lagoon, and *C. tasmanica* in Big lagoon and Gibbs Lagoon.

The microcrustacean diversity observed in this study should be treated with caution. The spatial variation between samples from different weedbeds, the lack of both replicates and truly quantitative sampling of lagoons, limit the value of the observations obtained. The abundant epiphytic growth in the weedbeds is likely to be a significant source of food for littoral microcrustaceans, as is fine particulate organic matter released from decomposing macrophytes. It is likely that the diversity of microhabitats and food sources occurring within the weed bed habitats contributes to the species richness of microcrustacean communities in the study area. Shiel (1976) discusses the concept of spatial microhabitat separation, where microcrustacean species are restricted to localised areas of a weedbed habitat or to particular weedbeds because of their differing food requirements, or because of their ability to move over or through a particular substrate It is possible with greater frequency of sampling and a more rigorous sampling techniques that more species would be recorded from these lagoons.

8.6.2 Limnology

The Bruny Island lagoons are too shallow and exposed to strong onshore winds to allow for thermal stratification. The lagoons are polymictic and those with extensive open waters may be turbid with resuspension of bottom sediments. None of the lagoons has direct connection to the sea so water chemistry is principally one of moderate salinity, acidic to circum-neutral pH with Little Lagoon relatively alkaline, moderate to extreme dystrophy and a seawater ionic character. Most have an indeterminate shoreline attributed to the varying volume of the respective lagoons depending upon the time of year.

Gilvin (g440)- the intense colouration of the water in D'arcys Lagoon and Gibbs Lagoon is mainly autochthonous in origin and is attributed to the macrophytic growth within the lagoons Little Lagoon's dystrophic nature is more characteristic of sedgeland waters of Western Tasmania (Buckney & Tyler 1973b) With almost no aquatic macrophyte vegetation to contribute to humic material, the dystrophic nature of this lagoon is derived from allochthanous DOM from the surrounding coastal heath and sedgeland

Bowling *et al.* (1986) classified lakes with g440>c. 10.0 m^{-1} as highly coloured waters and on this criteria then all of the Bruny Is. lagoons fall into this category with several extremely dystrophic or 'blackwater'. Temporal variation in colour is apparent, particularly for the more ephemeral Gibbs, D'Arcys and Bains lagoons. Big Lagoon does not show the same degree of change as the others due to its larger volume and permanent nature. Bowling *et al.* (1986) and Bowling *et al.* (1993) made the point that in Tasmanian inland waters there was insufficient colour variation within a waterbody to change its classification. This may be true for inland permanent standing

bodies of water, but for ephemeral and astatic coastal freshwaters, it appears colour may vary by an order of magnitude. Such change is attributed to leaching of allochthanous DOM following rain events and a varying volume of water within the lagoon basin.

8.7 CONCLUSION

The presence of *Boeckella nyoraensis* in the Bruny Is. lagoons is attributed to the high levels of DOM. Similarly its presence in the highly dystrophic Cape Naturaliste lagoons (Chapter 4 & 6) is further evidence that this species favours shallow, ephemeral waters of variable high to extreme dystrophy. Limnologically, morphometrically and hydrologically the Bruny Is. lagoons are similar in many respects to the dystrophic Cape Naturaliste lagoon of North East Tasmania.

Besides housing this rare copepod, the Bruny Island lagoons are rich sites for other microcrustacean species and are significant lagoons, similar to those in the south west World Heritage Area, and Fraser and Morton Islands having in common the fact they are located in close proximity to the sea and on a siliceous substratum which contributes little in the way of ions by weathering (Bayly 1964a). Much has been made of the ecological significance and the biota contained within of the lake districts of Fraser Is. (Bayly 1964a; Bayly *et al.* 1975; Arthington *et al.* 1986); Stradebroke Is. (Bensink & Burton 1975; Lee-Manwar *et al.* 1980). Yet the ignorance and lack of interest by researchers in the diversity, richness of the microinvertebrate fauna of Tasmanian waterbodies is very apparent by the dearth of published material available.

CHAPTER 9
AQUATIC MICROCRUSTACEAN BIOGEOGRAPHY OF FRESHWATER COASTAL DUNE LAKES OF NE TASMANIA

9.1 ABSTRACT

Disjunct population distributions of freshwater microcrustacean species in NE Tasmania and southern Australia may be explained by Miocene and Quaternary paleoclimatic change, a concomitant change in the hydrological/limnological environment and existence of the Pleistocene peninsular landbridge between Tasmania and south eastern Australia

9.2 INTRODUCTION

The biogeographical relationships between the microcrustacean fauna of the dune lakes of NE Tasmania are explored in relation to the fauna from the coastal dune lakes elsewhere in Tasmania and also with southern mainland Australia and the Bass Strait Islands.

9.3 DISCUSSION

Biogeography must be based on sound taxonomy and on reliable collections. Such expertise in microcrustacea is still not widely available in Australia (Green & Shiel 1992), and the state of taxonomy for many cladoceran groups is in some confusion. This places limitations on many such ecological studies and surveys including the present one For example, rapid changes of community dominants can occur in in a matter of days or less as conditions change (Boon & Shiel 1990). While the zooplankton community is sensitive to and responds to environment changes, their use as indicators of change (natural or man-made, long or short term) depends on a good systematic knowledge Generally the zooplankton community of the NE lagoons investigated is dominated by *C. tasmanica tasmanica*, *C. gibbosa gibbosa,* or by *Daphniopsis* The littoral community is dominated by Chydorids, *Ceriodaphnia* and *Simocephalus*

Calamoecia gibbosa was originally described from Tasmania in 1950 from Lake Dulverton. Subsequently it was recorded from eastern Tasmania, Bass Strait Islands and the far south east of South Australia A different form of this species was recorded from Western Australia and given subspecific status as *Calamoecia gibbosa newmannensis* (Bayly 1979), while the Tasmanian form is known as *Calamoecia gibbosa gibbosa.* Bayly (1979) proposed that *C. gibbosa* extended along much of the southern margin of Australia during more pluvial times, and with the onset of aridity these became isolated into eastern and western groups This vicariant geographic isolation in the Pleistocene led to genetic divergence resulting in the marked phenotypic differences of the two subspecies.

A parallel situation exists for *Calamoecia tasmanica.* This species was first described from Bruny Island, Tasmania by Smith (1909) and subsequently recorded from freshwater coastal dune lakes and acidic-humic inland waters of Tasmania, the Bass Strait Islands (Walsh 1991) and the eastern coastal regions of mainland Australia. Forms of this species occur in Western Australia and on the basis of several morphological distinctions the eastern (*C. tasmanica tasmanica*) and western Australian (*C. tasmanica subattenuata*) forms are separated subspecifically (Bayly 1979,1984).

The subspecific divergence of *C. tasmanica* and *C. gibbosa* of eastern Australia from the WA populations may be explained by past climate change (Bayly 1984). Some 20 million years ago in the early Miocene, the southern regions of Australia experienced a humid climate that penetrated far inland (Bowler 1982). Extensive freshwater lakes would have existed where salt lakes now dominate. Bowler (1982) considered the climate sufficiently moist to allow the lakes to exist year round. Such a climate would encourage populations of freshwater calanoids across southern

Australia. By the late Miocene, 6 million years ago, climate change with pronounced and intense seasonal aridity along southern Australia, separated the east-west continuum into two segments. By the late Pliocene, 2.5 million years ago, the present climate of Australia had developed and by one million years ago central Australia was dry (Bowler 1982). There was a period during the late Pleistocene with a return to similar pluvial conditions described for the early Miocene

Bayly (1984) regards the Western Australian populations of *C. gibbosa* as relictual, and a product of vicariant geographical isolation. The situation for *C.tasmanica tasmanica* in east Australia and *C. tasmanica subattenuatta* in the west, while not unlike that of *C. gibbosa,* is more complex (Bayly 1979).

The separation of the Tasmanian freshwater calanoid copepod populations from the Australian mainland may be explained similarly Tasmania is separated from Australia by Bass Strait. The strait is approximately 250km wide and less than 100m deep (**Figure** 9.1). During the late Tertiary and the Pleistocene there were a number of Ice Ages with marked oceanic eustatic changes. In glacial and interglacial periods levels reached up to 200m below and 40m above current sea level (Galloway & Kemp 1981) During periods of lowered sea levels there would have been a land connection between Tasmania and Australia Thus the flooding of Bass Strait would act as a vicariant event, and the exposure of the Strait would offer a mechanism for dispersal (Horwitz 1988).

During the last major global Ice Age between 75,000 and circa 10,000 years BP, sea levels were probably 100-120m below present levels (Jennings 1971; Galloway & Kemp 1981). During this period Tasmania would have been the southern most part of a peninsula linked to mainland Australia by a land bridge (**Figure** 9.1) The coastal north eastern portion of Tasmania would have formed the southern fringe of a large continental sandy plain of low relief with occasional granitic outcrops, which is now essentially the floor of Bass Strait

There is some evidence to suggest that wind conditions at this time were stronger than those of today (Bowden 1983), resulting in aeolian mobilisation of these continental sand plains and in dune formation. These would have been conditions similar to that which occurs in central Australia today

On the basis of contemporary patterns, rainfall is more predictable and abundant in coastal regions. It is fair to assume that this phenomena occurred in the Pleistocene in coastal margins of southern Australia. De Deckker (1986) suggested that a chain of lagoons along the coastal margins would have provided a refuge for aquatic biota from increasing aridity. Lunettes, swamps and lagoons would have formed in the swales and gutters of the longitudinal dunes at the coastal margins of this sandy continental plain (i.e. Bass Strait). Such a system would have provided a corridor for the coastwise movement of some component of the aquatic biota from Australia to Tasmania and vice versa.

The question of how the aquatic microbiota would have crossed the now exposed Bass Strait may be answered by passive diffusion (Pielou 1979) of resting stages by wind and waterfowl over a period of many generations. Inland, the arid conditions experienced by this continental sand plain would lend to the possible formation of saltpans and lunettes that would favour more halobiont species such as *C. clitellata, Daphniopsis australis* and *Daphniopsis pusilla.*

Together these wetlands provided a continuum of habitats from Tasmania to south eastern Australia for the freshwater fauna. With the change in climate and marine transgression of Bass Strait circa 10,000 BP, the populations of freshwater calanoids and cladocerans were separated into now disjunct distributions with the southern Australian mainland fauna, that of Bass Strait Islands

and that of north east Tasmania.

The pronounced precipitation gradient from west to east across Tasmania is due to orographic rainfall from moist westerly air streams intercepted by the west coast highlands. When sea level was lower than that of today, Bowden (1983) and Colhoun (1978) argued that the west coast ranges, due to increased elevation relative to sea level, would have increased the precipitation gradient. This, coupled within increased continentality due to drainage of Bass Strait, would have increased the aridity of north eastern and eastern Tasmania, as this would have removed the source of moisture for the north westerly circulation patterns whose winds today bring seasonal and occasional rains to northeastern Tasmania. In addition, intense low pressure systems that currently move eastwards through Bass Strait and also bring moisture to north eastern Tasmania would have been similarly affected (Bowden 1983)

The increased aridity and pronounced seasonality in rains of eastern Tasmania as a whole during this period of the Pleistocene would be reflected in the increased ephemerality, salinity and astaticity of the coastal freshwater dune lakes and lagoons, and in the inland shallow wetlands, swamps and lakes of eastern Tasmania during this period All of which would have favoured the spread of halobiont species and those with lifecycles adapted to temporary waters.

It is of interest that today in the lowland lakes (both coastal and inland) of eastern Tasmania the cladoceran and calanoid copepod fauna is dominated by species that possess strong seasonality in their respective life histories and possess life cycle strategies to cope with seasonal temporary waters (Walsh 1991).

9.4 CONCLUSION

Thus the flooding of Bass Strait as sea level rose would act as a vicariant event, while the exposure of the Strait offered a mechanism for passive dispersal (Horwitz 1988) by diffusion of resting stages over a period of many generations. Based on current population distributions and the relative abundance of *B. nyoraensis*, *C. gibbosa* and *C. australis* in Tasmania relative to mainland southern Australia the following questions arise:

(1) Did these species spread from Tasmania to the southeastern region of mainland Australia, with *C. gibbosa* then extending from there to Western Australia?
(2) Did these species and *C. tasmanica tasmanica* extend from southeastern continental Australia into Tasmania via the Bass Strait landbridge?
(3) Or are these relict populations?

Based on the prevalence of *C. gibbosa* in Tasmania and paucity of distribution records for southern Australia it is more likely that first option is true for this species. Conversely, due to the extensive distribution of *C. tasmanica* on the eastern Australian seaboard and across southern Australia, this species is felt to have dispersed to Tasmania from the mainland. Similarly, the most likely scenario for the halobiont species of *Daphniopsis* and *C. clitellata* is also that they came across from southeastern continental Australia into Tasmania via the Bass Strait landbridge

When the above species appeared in Tasmania is open to conjecture . These species are widely distributed over their respective ranges from Tasmania to southern Australia. The land connection between Tasmania and the mainland has been broken and restored on numerous occasions since the

Miocene. There have been up to nine glacial-interglacial episodes in the Quaternary with periods of low sea levels. The inundation of Bass Strait would have divided the above fauna into two vicariant populations. Exposure of Bass Strait would have re-established contact allowing gene flow between the two previously isolated populations. Successive appearances and disappearances of barriers (i.e. vicariant events) may lead to the concentration of numbers of species in the centre of the common range; in some cases however, as a result of local extinctions, the greatest number of species occur in some peripheral areas (Banarescue 1990). This may explain the high microcrustacean species diversity of the north east lagoons and of the calanoid copepod fauna for Tasmania as a whole, compared to mainland Australia.

The paucity of records for many of the other microcrustacean species, due to poor taxonomic resolution and the few individuals working in this field, make comment on the remainder of the species difficult.

The lagoons of north-east Tasmania provide a good limnological subset of coastal freshwater body types in Tasmania. These lagoons are rich in diversity with biogeographical affinities to southern-eastern Australia and Western Australia. The lagoons of the north east coastal plain differ biologically in microcrustacean diversity from other freshwater coastal dune waterbodies of Tasmania.

CHAPTER 10
SYNTHESIS OF DISSERTATION

10.1 GENERAL DISCUSSION

This thesis documents a reconnaissance of coastal freshwater lagoons, providing baseline data for further work highlighting the importance of this otherwise little known "class" of freshwater bodies. Coastal freshwater lagoons from several localities around the Tasmanian mainland were investigated as an holistic study of the limnology and microcrustacean ecology of this relatively neglected group of Tasmanian waterbodies. The Bass Strait Islands were investigated but results are not detailed here.

The main objectives of this study were:

(1)- **to describe the microcrustacean fauna of freshwater coastal dune lakes from Tasmania and offshore islands.**

The Microcrustacean fauna of freshwater coastal dune lakes from Tasmania and offshore islands are described in Chapter 4, Chapter 7 and Chapter 8 The study demonstrated that the microcrustacean species occurring within the coastal lagoons of the North East Coastal plain form a very rich assemblage in comparison with those of other areas of Australia. This is probably due to the marked seasonal variation in the aquatic environment of this region brought about by the winter rainfall maximum and summer minimum. High species diversity is associated with seasonal drying. The hydrological regime is similar to the "Wet and Dry" of tropical monsoonal North Australia The expansion of the aquatic environment in the "Wet season", with the associated proliferation of aquatic macrophytes, creates a wide range of physical habitats for littoral microcrustaceans. 30 cladoceran species and 4 copepod species were from littoral habitats.

Littoral spatial and temporal habitat heterogeneity is influenced by seasonally fluctuating water levels, particularly within the aquatic macrophyte communities of the more shallow, extensively vegetated lagoons. Seasonal changes in the aquatic physical and chemical environment influence the microcrustacean communities and possibly follow similar yearly patterns.

(2)- **to investigate the physicochemical limnology of permanent, markedly astatic and ephemeral lagoons.**

The physicochemical limnology of permanent, astatic and ephemeral lagoons is described in Chapter 3. Limnological reconnaissance of the North East Coastal plain revealed most of the lagoons to be shallow, polymictic, of variable dystrophy and to have extensive growths of submerged and emergent macrophytes Seasonal changes in conductivity due to evaporative concentration followed by dilution during rainfall were evident in the shallower wetlands. Most were fresh to slightly saline. Ionic composition was dominated by Na^+ and Cl^- . The majority of lagoons were circum-neutral and reflect the influence of the calcareous sand; these conditions were similar to those in lagoons on the Bass Strait Islands, but in contrast to the dystrophic lagoons of the West Coast and Bruny Island, located on vegetated and stable siliceous dune systems.

The dune lakes of the north eastern coastal plain of Tasmania are similar in mode of origin and age to other coastal freshwater dune lakes in Tasmania. However, these dune lakes differ in that they are markedly astatic relative to most Tasmanian lagoons. Water levels of these lagoons fluctuate considerably and as a result shorelines are rather indefinite, dependent upon basin morphometry, season and severity of the summer. Water levels are determined by rainfall-evaporation relationships and the internal seepage patterns of the lagoon basin and catchment. The lagoons of North East

Tasmania could be separated into 3 groups (permanent, astatic and ephemeral) based on limnological properties as influenced by their respective hydrological regimes. In this they are similar to the lagoons of Bruny Island (Chapter 8).

(3)- **to investigate the role of permanent and seasonal lagoons in supporting different microcrustacean species/communities**

Limnologically each lagoon is a dynamic system that may vary in many ways from even its nearest neighbour (Chapter 5). Each lagoon is distinguished by a combination of features, including landform, morphometry and chemical composition of its waters, which are a result of short and long term environmental changes. The seasonality of the lagoons has important ecological implications for the invertebrate faunae of these waterbodies.

Permanent and seasonal lagoons supported differing microcrustacean species and communities (Chapter 6). The taxonomic diversity of the microcrustacean community may be viewed as a paradox analogous to the "paradox of the plankton" identified by Hutchinson (1961), who showed a contradiction between theoretical population ecology (principle of competitive exclusion) and empirical data (plankton generally comprise a large number of species, occupying the same niche) The paradox of high species diversity in this instance may be solved similarly. For competitive exclusion to occur, the competing populations are required to operate within constant environmental conditions. However the littoral environment is disturbed in different ways (temperature, turbidity, fluctuations in water chemistry and water level, variable conductivity) on a time scale short enough to alter the habitat of competing microcrustacean populations before competitive exclusion occurs. Additional mechanisms such as differing life cycles, mortality rates, predation, growth rates and the occurrence of littoral microhabitats all encourage co-existence of populations. The spatial and temporal structuring of planktonic communities into microzones of different niches would further complement the parallel existence of different populations.

Each lagoon differs from its closest neighbour in the community response to environmental cues experienced in each lagoon. The NE shallow coastal lagoons are dynamic systems in a constant state of flux. In contrast, the lagoons of the West Coast can be differentiated from the North East lagoons in species diversity and habitat stability (Chapter 7).

The West Coast lagoons have relatively large areas of open deep water, lack a well defined littoral zone, have relatively simple macrophyte communities, are deep relative to surface area and have stable water levels and relatively definite shorelines The high rainfall of the region ensures even shallow lagoons usually contain water. The "stability" of the lagoons reduces temporal and spatial habitat heterogeneity Therefore niche diversity, and as a consequence species diversity, is low. Site species paucity of the microcrustacean fauna is in marked contrast to that recorded for the dune lakes of NE Tasmania. The West Coast calanoid copepod species are planktonic, whereas the diverse cladoceran fauna of the NE coastal plain generally live at the sediment water interface, burrow in the sediment floc or climb on emergent vegetation, i e. they are littoral or epibenthic in habit or prefer shallow open vegetated waters

(4)- **to determine biogeographical relationships in the microcrustacean fauna of Tasmania, Bass Strait Islands and SE Australia.**

Biogeographical relationships in the microcrustacean fauna of Tasmania and southern mainland

Australia are discussed in Chapter 9. While the lakes and lagoons of the coastal province may be separated from the other two provinces based on their common differences from these inland lakes, the water bodies in this grouping are by no means homogenous in character. The coastal limnological province is not continuous around the island and regional differences occur Physicochemically the lagoons of N.E Tasmania are similar to other freshwater coastal dune lakes of the Coastal Limnological Province of Tasmania. They differ, however, in planktonic microcrustacean biological diversity. This may be attributed to the ephemeral-astatic, seasonal nature of these lagoons. Disjunct population distributions of freshwater microcrustacean species in NE Tasmania and southern Australia may be explained by Miocene and Quaternary paleoclimatic change, a concomitant change in the hydrological/limnological environment and Pleistocene existence of the peninsular landbridge between Tasmania and south eastern Australia

The littoral planktonic microcrustacean community tends to be dominated by cladocerans, especially in those lagoons with extensive fringing submerged and exposed aquatic macrophytes

(5)- **to investigate life history and ecology of dominant species.**

The life histories and ecology of several taxa are discussed in some detail in Chapter 4 and briefly in Chapter 6. In Chapter 6 species abundance and temporal and spatial distributions are also discussed in relation to habitat heterogeneity. The greater the spatial and temporal habitat heterogeneity, the greater the species diversity.

(6)- **the classification of microcrustacean species into feeding groups by investigation of diet and feeding regimes.**

This was not investigated due to constraints in time. This is an area worthy of further investigation into the ecology, trophic relationships and degree of competition within microcrustacean communities.

10.2 ECOLOGICAL IMPORTANCE OF COASTAL DUNE LAKES

The significance of these habitats is highlighted under the RAMSAR Convention with several of the NE lagoons being nominated as "Wetlands of International Importance." The qualifying criteria relate to "wetlands" values in terms of uniqueness, value of biodiversity and as waterbird habitats. The RAMSAR Convention considers that a wetland qualifies as being of international importance if it meets at least one of its major criteria:

1) Criteria for representative or unique wetlands
2) Criteria based on plants and animals
3) Specific criteria based on water birds

The NE lagoons, as a group, meet all of the above criteria in that they are representative of natural and near natural wetlands characteristic of a biogeographical region, and play a substantial hydrological, biological and ecological role in the natural functioning of a coastal system; individual lagoons support rare and endangered species, and together the lagoons are of special value in maintaining the genetic and ecological diversity of a region because of the quality and peculiarities of their fauna and flora; and their support of substantial numbers of individuals from particular groups

of water birds.

10.3 CONCLUSION

Limnologically, Tasmania is acclaimed by some (Tyler,1992) as a 'lakeland' containing unique, rare and endemic microorganisms whose discovery has showed some insight into evolutionary pathways and biogeographical relationships. On the basis of mode of origin, age and limnological characteristics, the coastal waterbodies differed markedly from the inland waters of Tasmania. Tasmanian inland lakes are mainly of Pleistocene glacial origin and on Precambrian-Ordovician schists or Jurassic dolerite. The coastal lakes and lagoons are on Holocene aeolian siliceous or carbonaceous sands of marine origin. Limnologically the coastal lakes and lagoons are more dystrophic, have higher conductivities and levels of gilvin and DOC, are of variable pH, and are much more turbid than natural inland Tasmanian waterbodies. They also tend to be much shallower in depth, display distinct seasonal limnological trends and most are astatic in nature.

This seasonality in limnological conditions and the differing degree of ephemerality of the lagoons is reflected in the biological diversity. Ecologically the coastal lagoons represent an environmental mosaic of differing aquatic habitat types. The speciose zooplankton assemblage of Tasmanian coastal lakes and lagoons differ from the monospecific calanoid copepod zooplankton assemblages of Tasmanian natural inland waters, with up to seven species of calanoid copepods present in the zooplankton assemblage. This diversity is also reflected in the cladoceran fauna with individual species replacing the calanoid fauna as the dominant plankton. This difference between inland lakes and the coastal lagoons is further evidence for the existence of a Coastal Limnological Province in Tasmania.

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APPENDIX

APPENDIX 1 NE Tasmanian Dune Lake physicochemical data 1991-1992

Site	Date	pH	K25 uS/cm	Turbidity	g440	Na	K	Ca	Mg	Cl	HCO3	SO4	D O.C	Chl 'a'
Cape Naturaliste No 1	18 8 91	6 2	490	2.00	10.478	110	3.1	15	16.7	19	11	55	17 6	
Cape Naturaliste No 2	18.8.91	6.5	570	4.00	5.585	155	4.6	20	22	245	28	68	13.7	
Cape Naturaliste No 4a	18 8 91	6.5	560	4.50	14 509								25 3	
Little Waterhouse	19 8.91	8 1	1240	1 00	3 742	300	9	78	51	515	235	130	41 3	
Bowlers Lagoon No1	23.9.91	8	920	0.55	6 218	185	120	30	17.9	22	235	16		
Cape Portland 3	23.9 91	8.5	11810	0.50	8 176	2720	99	165	335	5000	225	705	24.7	
Cape Portland 4	23 9 91	7.9	3240	0.40	12.954	515	18	76	65	945	250	170	41	
Cape Portland 5	23.9.91	7.8	6460	0 70	7 83	1200	31	110	210	2350	220	315	29.4	
Cape Portland 6	24 9 91	8 5	10800	0.90	13 702	2440	65	71	385	1730	750	440	53.6	
Tregaron No1	24.9.91	8 4	5660	0.50	8.751	1140	40	100	210	1950	440	220	58 7	
Tregaron No 2	24 9 91	7.9	2350	0.60	14 336	400	16.5	79	76	670	300	91	42 3	
Tregaron No1	6 11.91	8.6	6840	0.50	7.599	1320	41	92	235	2220	545	240	44 5	
Bowlers No 1	6.11.91	8	1003	0.50	3 224	160	6	30	30	265	200	7.5	17.9	
Cape Portland No 6 (W en	6.11.91	9 5	13450	2.00	6.276	4040	145	405	515	7350	290	3400	87 4	
Cape Portland No 6a	6.11 91	9.6	2570	0 45	10 018	395	19	15	145	545	810	16	40.1	
Cape Portland No 6	6.11.91	9.3	13530	0.95	4.779	2850	70	27	465	4900	700	500	169.1	
Cape Portland No 4	6 11.91	8 9	5670	0.85	8.463	2220	74	185	295	4050	315	695	40 7	
Cape Portland No 2	6.11.91	8.5	13420	0 50	8.118	2880	105	225	345	5300	200	975	41 6	
Cape Naturaliste No.1	13 1.92	6 5	853	0.45	26.542	165	5.9	11	22	330	35	34	70 8	0.16
Cape Naturaliste No.2	13.1.92	6 4	640	0 50	45 715	100	2.9	8	14	390	22	39	85.5	0.00
Cape Naturaliste No.4a	13.1.92	6.7	857	3 00	18 021	140	5.3	12	19	250	21	55	50.7	0.00
Cape Naturaliste No.4c	13 1.92	6.1	1456	1 00	13.242	3550	82	240	640	6000	370	850	85.1	0.75
Cape Naturaliste No.5a	13 1 92	4 7	1359	4 00	18.136	230	5.5	15	37	420	2	105	61 2	1 25
Tregaron No.1	14.1 92	8 7	8340	3 50	6.679	1830	58	67	310	3230	360	310	89 4	
Cape Portland No 5	14 1.92	7 2	13120	70.00	27.291	315	10	13	41	475	25	105	260.8	0.00
Cape Portland No 6	14 1.92	8.1	15480	35 00	6.794	3900	100	53	620	6600	900	710	173 4	0.32
Bowlers No 1	14 1.92	7.7	1091	1 50	4 203	160	7	52	31	250	240	<5	21.9	0.00
Bowlers No 2	14.1.92	6 7	1011	0.40	4.606	185	8	36	34	300	175	8.9	24.1	0.00
Little Waterhouse	15.1 92	7.7	1807	2.00	4.03	310	8.5	67	50	510	180	100	31	
Big Waterhouse	15 1.92	7.5	627	2.00	8.348	90	6.3	26	16	145	77	25	24.1	1 23
Blackmans Lagoon	21.1 92	8 1	2360	0 55	4.203	400	17.5	54	68	700	230	56	38 2	0.21
Cape Naturaliste No 1	16.3.92	7.5	1507	0 55	22.742	270	8	15	32	465	28	51	105 0	
Cape Naturaliste No 2	16 3.92	6.5	1202	0.40	50 205	220	6.9	16	29	380	29	46	108 5	
Cape Naturaliste No.4a	16 3 92	6 4	1363	1 20	14 739	240	7 8	18	32	395	20	84	77 8	
Cape Naturaliste No.4b	16 3.92	6 2	2810	1 20	20.554	435	12	49	70	810	20	215	70.1	
Tregaron No.1	17 3.92	8.9	12980	2.20	9.845	3210	96	90	530	5580	430	520	143 4	
Cape Portland No 5	17.3.92	8 1		1 50	5 758	10000	230	500	1700	17600	400	2300	115 6	
Cape Portland No.6	17 3 92	8 5		12.00	15 948	10500	265	68	1600	17000	1350	1800	105 7	
Bowlers No.1	17 3.92	8 1	1360	1 80	5 182	190	7	63	38	310	290	<5	26 3	
Bowlers No 2	17 3.92	7 6	1480	0.60	6 218	210	7.5	49	45	360	250	<5	30 2	
Big Waterhouse	18.3 92	7.8	740	0 80	8.579	99	6.9	31	18.5	160	99	25	24 8	
Little Waterhouse	18.3.92	7.7	2300	0 55	3.397	360	9 3	76	61	620	210	110	35 8	
Blackmans	18 3.92	8.7	2710	1.25	3.512	480	21	52	83	810	230	63	41 5	
Cape Naturaliste No 5a	13 7 92	4.4	750	2.20	13.357	115	3 4	7.3	17	195	1.6	58	28 1	0 11
Cape Naturaliste No 5b	13.7.92	5.8	800	0.95	11.515	130	2.8	6 2	18	225	6 7	37	27 8	0.16
Cape Naturaliste No 4c	13 7.92	5 3	680	2.60	16 582	135	4	4.6	17	190	4 5	37	31 2	0 00
Cape Naturaliste No 4a	13 7.92	6.3	810	0.95	10.824	130	4.8	11	17	230	13	40	32 6	2 85
Cape Naturaliste No 1	13.7 92	6.4	720	0.66	20 036	120	4	7.8	13.8	205	13	24	32 3	0 00
Cape Naturaliste No 2	13.7.92	6.2	590	0 63	26.715	98	3 1	7 3	11	160	13	15	37.1	0 11
Bowlers No 1	14 7.92	7.9	11500	0.70	3.915	155	5 6	52	32	270	270	5.2	17 8	0 00
Bowlers No 2	14.7 92	7.3	1000	0.34	1.152	115	3 6	73	29	190	295	19.7	11 2	0 00
Cape Portland No 5	14.7 92	8 5	12100	25 00	4.376	3000	79	220	530	2070	250	820	40 7	
Cape Portland No 6	14.7.92	8 6	11400	6 50	6.218	3040	77	60	470	5350	760	530	56.8	1 23
Cape Portland No 2	14 7.92	8 2	9200	0.70	8.982	2080	74	250	280	3980	250	775	25 6	0 03
Cape Portland No 4	14 7.92	8 6	5700	1.10	5.758	1140	36	120	165	2020	230	390	36 7	0 00
Blackmans Lagoon	15.7 92	6.6	12300	1.60	16 582	195	6 9	26	35	345	60	74	36 7	
Big Waterhouse	15 7.92	6.5	540	1 25	12 897	83	4	17	14	130	57	24	28 1	
Little Waterhouse	15 7 92	8	1880	0.56	3 224	300	9	78	51	515	250	130	22.5	0 00
Tregaron No1	14.7 92	8.8	8400	1 20	7.139	1940	52	71	320	3500	555	295	52 5	0.13

All major ions and DOC in mg/l
Chl 'a' in $\mu g/l$

SPECIES	CN 1	CN 1	CN 2	CN 4a	LLW	BMANS L	BL 1	TREG 1	TREG 2	CP 3
	2/7/90	18/8/91	18/8/91	18/8/91	19/8/91	19/8/91	23/9/91	24/9/91	24/9/91	25/9/91
CALANOID										
Boeckella sp				+						
Boeckella major			+	+						
Boeckella nyoraensis										
Boeckella propinqua propinqua		+	+	+		+	+		+	
Boeckella symmetrica					+					
Boeckella tnarticulata								+	+	
Calamoecia australis			+	+			+			
Calamoecia clittelata										+
Calamoecia gibbosa gibbosa	+	+	+	+		+		+	+	
Calamoecia tasmanica tasmanica										
Gladioferens pectinatus										
Gladioferens spinosus										
Hemiboeckella searli			+	+		+				
CLADOCERA										
Bosminidae										
Bosmina meridionalis	+									
Chydoridae					+	+				
Alona sp										
Alona quadrangularis										
Archepleuroxxus baylyi										
Biapertura sp.										
Biapertura affinis.										
Biapertura longiqua										
Biapertura rigidicaudis.										
Biapertura setigera.										
Camptocercus australis							+			
Chydoris cypretella							+			
Chydorus spp.		+								
Pseudochydorus sp										
Dunhevedia sp.										
Dunhevedia crassa									+	
Ephemeroporus cf. barrosi										
Graptoloberis sp.										
Pleuroxus sp										
Rak sp										
Daphniidae										
Ceriodaphnia sp.										
Ceriodaphnia laticaudata					+	+				
Ceriodaphnia quadrangula									+	
Daphnia carinata					+	+	+	+	+	
Daphnia longicephala			+							
Daphniopsis australis										
Daphniopsis pusilla										+
Ilyocryptus sp										
Ilyocryptus spinifer										
Scapholoberis kingi										
Simocephalus sp							+			
Simocephalus expinosus australiensis										
Simocephalus vetulus					+					
Macrothricidae										
Macrothrix sp A										
Macrothrix sp B										
Macrothrix breviseta							+			
Macrothrix capensis										
Macrothrix carinata										
Macrothrix pectinatus										
Macrothrix spinosa										
Neothrix armata										
Moinidae										
Moina australiensis										

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BL = Bowlers Lagoon
TREG = Tregaron Lagoon

SPECIES	CP 4	CP 5	CP 6	TREG 1	BL 1	CP 4	CP 6	BMANS L	BLW	LLW
	25/9/91	25/9/91	25/9/91	11/6/91	11/6/91	11/6/91	11/6/91	28/11/91	28/11/91	28/11/91
CALANOID										
Boeckella sp										
Boeckella major	+									
Boeckella nyoraensis										
Boeckella propinqua propinqua										
Boeckella symmetrica								+		
Boeckella triarticulata	+	+	+	+		+	+			
Calamoecia australis										
Calamoecia clittelata	+		+							
Calamoecia gibbosa gibbosa				+						
Calamoecia tasmanica tasmanica										
Gladioferens pectinatus								+	+	
Gladioferens spinosus										
Hemiboeckella searli										
CLADOCERA										
Bosminidae										
Bosmina meridionalis										
Chydoridae										
Alona sp										
Alona quadrangularis										
Archepleuroxxus baylyi										
Biapertura sp					+					
Biapertura affinis										
Biapertura longiqua										
Biapertura rigidicaudis.										
Biapertura setigera										
Camptocercus australis					+					
Chydoris cypretella										
Chydorus spp									+	+
Pseudochydorus sp.									+	
Dunhevedra sp.										+
Dunhevedia crassa										
Ephemeroporus cf. barroisi										
Graptoloberis sp										+
Pleuroxus sp										
Rak sp										
Daphniidae										
Ceriodaphnia sp.	+			+					+	
Ceriodaphnia laticaudata	+					+				
Ceriodaphnia quadrangula										
Daphnia carinata	+	+		+				+		+
Daphnia longicephala										
Daphniopsis australis										
Daphniopsis pusilla		+					+			+
Ilyocryptus sp										
Ilyocryptus spinifer										
Scapholoberis kingii										
Simocephalus sp										
Simocephalus expinosus australiensis										
Simocephalus vetulus										
Macrothricidae					+					
Macrothrix sp A				+						
Macrothrix sp B				+						
Macrothrix breviseta										
Macrothrix capensis	+					+	+			
Macrothrix carinata										
Macrothrix pectinatus										
Macrothrix spinosa										
Neothrix armata										
Moinidae										
Moina australiensis										

N = Cape Naturaliste
P = Cape Portland
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L = Bowlers Lagoon
REG = Tregaron Lagoon

SPECIES	CN 1	CN 2	CN 4a	CN 4c	CN 5a	CN 5b	TREG 1	LLW	BLW	BMANS L
	13/1/92	13/1/92	13/1/92	13/1/92	13/1/92	13/1/92	14/1/92	15/1/92	15/1/92	21/1/92
CALANOID										
Boeckella sp.				+						
Boeckella major		+	+							
Boeckella nyoraensis										
Boeckella propinqua propinqua			+	+						
Boeckella symmetrica								+		
Boeckella triarticulata							+			+
Calamoecia australis						+				
Calamoecia clittelata										
Calamoecia gibbosa gibbosa	+	+	+	+			+			
Calamoecia tasmanica tasmanica					+					
Gladioferens pectinatus										
Gladioferens spinosus									+	
Hemiboeckella searli										
CLADOCERA										
Bosminidae										
Bosmina meridionalis			+	+	+					
Chydoridae										
Alona sp										
Alona quadrangularis			+							
Archepleuroxxus baylyi										
Biapertura sp										
Biapertura affinis			+							
Biapertura longiqua										
Biapertura rigidicaudis.										
Biapertura setigera.		+								
Camptocercus australis			+			+				
Chydoris cypretella										
Chydorus spp										
Pseudochydorus sp										
Dunhevedia sp										
Dunhevedia crassa		+								
Ephemeroporus cf. barroisi										
Graptoloberis sp										
Pleuroxus sp										
Rak sp										
Daphniidae										
Ceriodaphnia sp		+								
Ceriodaphnia laticaudata										
Ceriodaphnia quadrangula	+									
Daphnia carinata										
Daphnia longicephala										
Daphniopsis australis										
Daphniopsis pusilla										
Ilyocryptus sp			+	+	+					
Ilyocryptus spinifer	+	+								
Scapholoberis kingi										
Simocephalus sp										
Simocephalus expinosus australiensis										
Simocephalus vetulus	+					+		+	+	
Macrothricidae										
Macrothrix sp A						+				
Macrothrix sp B										
Macrothrix breviseta										
Macrothrix capensis										
Macrothrix carinata										
Macrothrix pectinatus										
Macrothrix spinosa										
Neothrix armata			+	+					+	
Moinidae										
Moina australiensis										

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SPECIES	CN 2	TREG 1	BL 1	BL 2	CP 5	CP 6	BLW	LLW	BMANS L	CN 1
	16/3/92	17/3/92	17/3/92	17/3/92	17/3/92	17/3/92	18/3/92	18/3/92	18/3/92	13/7/92
CALANOID										
Boeckella sp										
Boeckella major	+									
Boeckella nyoraensis										
Boeckella propinqua propinqua										
Boeckella symmetrica								+	+	
Boeckella triarticulata										
Calamoecia australis										
Calamoecia clittelata					+					
Calamoecia gibbosa gibbosa	+									
Calamoecia tasmanica tasmanica										
Gladioferens pectinatus										
Gladioferens spinosus							+			
Hemiboeckella searli										+
CLADOCERA										
Bosminidae										
Bosmina meridionalis										
Chydoridae				+						
Alona sp	+									
Alona quadrangularis										
Archepleuroxxus baylyi										+
Biapertura sp										+
Biapertura affinis.										
Biapertura longiqua	+									
Biapertura rigidicaudis.			+							
Biapertura setigera										
Camptocercus australis			+							+
Chydoris cypretella										
Chydorus spp.			+				+			+
Pseudochydorus sp										
Dunhevedia sp										
Dunhevedia crassa	+			+						
Ephemeroporus cf barroisi										
Graptoleberis sp				+			+			
Pleuroxus sp										
Rak sp										+
Daphniidae										
Ceriodaphnia sp										
Ceriodaphnia laticaudata				+			+	+	+	
Ceriodaphnia quadrangula										
Daphnia carinata								+	+	
Daphnia longicephala										
Daphniopsis australis										
Daphniopsis pusilla		+			+	+				
Ilyocryptus sp										
Ilyocryptus spinifer	+									+
Scapholeberis kingi										
Simocephalus sp										
Simocephalus expinosus australiensis				+						
Simocephalus vetulus	+		+				+	+		
Macrothricidae										
Macrothrix sp A			+							
Macrothrix sp B										
Macrothrix breviseta		+								
Macrothrix capensis										
Macrothrix carinata										
Macrothrix pectinatus			+							
Macrothrix spinosa										
Neothrix armata										
Moinidae										
Moina australiensis										

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SPECIES	CN 2	CN 4c	CN 5a	CN 5b	CP 2	CP 4	CP 5	CP 6	TREG 1	BL 1
	13/7/92	13/7/92	13/7/92	13/7/92	14/7/92	14/7/92	14/7/92	14/7/92	14/7/92	14/7/92
CALANOID										
Boeckella sp	+		+				+			
Boeckella major			+	+						
Boeckella nyoraensis			+	+						
Boeckella propinqua propinqua	+			+						
Boeckella symmetrica										
Boeckella triarticulata					+			+		
Calamoecia australis	+		+							
Calamoecia clittelata									+	
Calamoecia gibbosa gibbosa				+						
Calamoecia tasmanica tasmanica			+							
Gladioferens pectinatus										
Gladioferens spinosus										
Hemiboeckella searli	+									
CLADOCERA										
Bosminidae										
Bosmina meridionalis				+						
Chydoridae										
Alona sp										
Alona quadrangularis										
Archepleuroxxus baylyi										
Biapertura sp.										
Biapertura affinis.										
Biapertura longiqua										
Biapertura rigidicaudis.										
Biapertura setigera.										
Camptocercus australis	+		+				+			+
Chydoris cypretella										
Chydorus spp	+		+							
Pseudochydorus sp										
Dunhevedia sp.										
Dunhevedia crassa										
Ephemeroporus cf. barroisi	+									
Graptoloberis sp										
Pleuroxus sp										+
Rak sp	+									
Daphniidae										
Ceriodaphnia sp.										
Ceriodaphnia laticaudata	+									
Ceriodaphnia quadrangula										
Daphnia carinata		+	+	+		+				
Daphnia longicephala										
Daphniopsis australis										
Daphniopsis pusilla					+		+	+		
Ilyocryptus sp										
Ilyocryptus spinifer	+		+							
Scapheloberis kingii	+									
Simocephalus sp										
Simocephalus expinosus australiensis										
Simocephalus vetulus	+									+
Macrothricidae										
Macrothrix sp A										
Macrothrix sp B										
Macrothrix breviseta					+					
Macrothrix capensis										
Macrothrix carinata	+									
Macrothrix pectinatus	+									
Macrothrix spinosa						+				
Neothrix armata			+							
Moinidae										
Moina australiensis			+							

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SPECIES	BL 2	BMANS	BLW	LLW
	14/7/92	15/7/92	15/7/92	15/7/92
CALANOID				
Boeckella sp.				
Boeckella major				
Boeckella nyoraensis				
Boeckella propinqua propinqua				
Boeckella symmetrica		+	+	+
Boeckella triarticulata				
Calamoecia australis				
Calamoecia clittelata				
Calamoecia gibbosa gibbosa				
Calamoecia tasmanica tasmanica				
Gladioferens pectinatus				
Gladioferens spinosus			+	
Hemiboeckella searli				
CLADOCERA				
Bosminidae				
Bosmina meridionalis				
Chydoridae				
Alona sp				
Alona quadrangularis				
Archepleuroxxus baylyi				+
Biapertura sp.				
Biapertura affinis	+			
Biapertura longiqua				
Biapertura rigidicaudis.				
Biapertura setigera.				
Camptocercus australis				
Chydoris cypretella				
Chydorus spp				
Pseudochydorus sp				
Dunhevedia sp				
Dunhevedia crassa				
Ephemeroporus cf. barroisi				
Graptoloberis sp.				
Pleuroxus sp				
Rak sp				
Daphniidae				
Ceriodaphnia sp		+		
Ceriodaphnia laticaudata				+
Ceriodaphnia quadrangula				
Daphnia carinata				+
Daphnia longicephala				
Daphniopsis australis				
Daphniopsis pusilla				
Ilyocryptus sp				
Ilyocryptus spinifer				
Scapholeberis kingii				
Simocephalus sp.				
Simocephalus expinosus australiensis				
Simocephalus vetulus	+			
Macrothricidae				
Macrothrix sp A				
Macrothrix sp B				
Macrothrix breviseta				
Macrothrix capensis				
Macrothrix carinata				
Macrothrix pectinatus				
Macrothrix spinosa				
Neothrix armata				
Moinidae				
Moina australiensis				

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AVERAGE DISSIMILARITY	BETWEEN	GROUPS 2 & 1	is 90.7%			
	group 2	group 1				
Species	av abundance	av abundance	TERM	RATIO	%	CUM%
Daphniopsis pusilla	0.64	0.11	11.31	1.06	12.47	12.47
Boeckella triarticulata	0.36	0.21	7.23	0.76	7.98	20 45
Daphnia carinata	0.09	0.43	6.08	0.81	6.70	27.15
Calamoecia clittelata	0.27	0.07	5.78	0.60	6.37	33.52
Boeckella symmetrica	0.00	0.29	4.92	0.58	5.43	38.95
Simocephalus vetulus	0.00	0.29	4.50	0.58	4.97	43.92
Ceriodaphnia laticaudata	0.09	0.25	3.98	0.62	4.39	48.31
Camptocercus australis	0.18	0.14	3.72	0.55	4.10	52.41
AVERAGE DISSIMILARITY	BETWEEN	GROUPS 3 & 1	is 88.34%			
	group 3	group 1				
Species	av abundance	av abundance	TERM	RATIO	%	CUM%
Daphnia carinata	0.29	0.43	6.05	0.76	6.84	6.84
Calamoecia gibbosa	0.43	0.18	5.75	0.81	6.51	13.35
Simocephalus vetulus	0.29	0.29	5.15	0.74	5.83	19.18
Boeckella triarticulata	0.19	0.21	4.34	0.61	4.91	24.09
Boeckella symmetrica	0.05	0.29	4.28	0.60	4.85	28.94
Ceriodaphnia laticaudata	0.14	0.25	3.67	0.63	4.15	33.09
Camptocercus australis	0.24	0.14	3.47	0.60	3.93	37.02
Boeckella major	0.33	0.00	3.28	0.68	3.71	40.73
Boeckella propinqua	0.24	0.11	3.15	0.60	3.56	44.30
Chydorus spp.	0.19	0.18	3.13	0.60	3.54	47.84
Bosmina meridionalis	0.19	0.04	2.90	0.47	3.28	51.12
AVERAGE DISSIMILARITY	BETWEEN	GROUPS 3 & 2	is 89.79%			
	group 3	group 2				
Species	av abundance	av abundance	TERM	RATIO	%	CUM%
Daphniopsis pusilla	0.05	0.64	9.7	1.05	10.81	10.81
Boeckella triarticulata	0.19	0.36	6.08	0.75	6.78	17.58
Calamoecia gibbosa	0.43	0.18	5.85	0.81	6.52	24.1
Daphnia carinata	0.29	0.09	4.91	0.57	5.47	29.57
Calamoecia clittelata	0.05	0.27	4.64	0.58	5.17	34.73
Boeckella major	0.33	0.18	4.07	0.78	4.53	39.27
Camptocercus australis	0.24	0.18	3.66	0.63	4.08	43.35
Boeckella propinqua	0.24	0.18	3.56	0.64	3.97	47.32
Simocephalus vetulus	0.29	0.00	3.46	0.57	3.85	51.17

Group 1 = Permanent lagoons
Group 2 = Asatic lagoons
Group 3 = Ephemeral lagoons

Site	Date	pH	K25 uS/cm	Tn (NTU)	g440	Na	K	Ca	Mg	Cl	HCO3	SO4	DOC	Chl'a'
Big Waterhouse	23 11 93	8 10	2190 00	0 25	9 788	37 00	3 20	23 00	19 00	120 00	74 00	20 00	17 00	1 52
Big Waterhouse	17 12 93	8 80	543 00	0 30	13 127	71 00	3 70	18 00	14 00	120 00	69 00	21 00	21 00	0 71
Big Waterhouse	9 1 94	4 00	261 00	1 00	11 170	57 00	3 70	16 00	11 00	97 00	0 00	16 00	20 00	1 81
Big Waterhouse	9 2 94	7 30	659 00	1 50	11 395	64 00	4 10	18 00	12 00	110 00	68 00	16 00	22 00	1 17
Big Waterhouse	10 3 94	7 80	610 00	0 30	10 651	61 00	3 60	19 00	12 00	105 00	72 00	17 00	23 00	3 20
Big Waterhouse	6 4 94	8 10	620 00	0 30	8 291	70 00	4 10	20 00	13 00	110 00	81 00	17 00	22 00	1 81
Big Waterhouse	5 5 94	8 24	634 00	3 00	7 485	77 00	4 20	21 00	15 00	144 00	87 00	20 00	21 80	4 80
Big Waterhouse	2 6 94	8.14	660 00	0 25	6 333	80 00	4 50	27 00	16 00	140 00	110 00	20 00	19 60	2 99
Big Waterhouse	29 6 94	8 09	754 00	0 20	5 988	79 00	4 50	27 00	16 00	140 00	42 00	22 00	15 90	
Big Waterhouse	28 7 94	8 57	595 00	0 40	7 560	81 00	4 40	22 00	17 00	140 00	48 00	22 00	30 00	
Big Waterhouse	1 9 94	7 05	734 00	5 00	3 858	87 00	4 60	31 00	17 00	155 00	44 00	24 00	30 00	2 00
Big Waterhouse	13 10 94	9 07	707 00	0 30	4 779	88 00	4 50	27 00	17 00	155 00	41 00	81 00	27 50	0 45
Big Waterhouse	18 1 95	7 78	732 00	0 55	4 600	150 00	6 50	38 00	19 40	155 00	2 70	145 00	23 40	1 07
Big Waterhouse	3 2 95	8.12	740 00	2 55	4 830	140 00	6 00	36 00	19 40	160 00	4 80	145 00	23 10	0 67
Blackmans Lagoon	25 11 93	8 80	1540 00	0 50	3 684	290 00	9 70	41 00	51 00	540 00	215 00	42 00	16 00	3 81
Blackmans Lagoon	17 12 93	8 70	2100 00	0 10	4 261	300 00	11 00	47 00	54 00	570 00	225 00	42 00	20 00	0 16
Blackmans Lagoon	9 1 94	8 10	942 00	1 00	2 648	115 00	4 60	21 00	23 00	200 00	105 00	21 00	14 00	0.32
Blackmans Lagoon	9 2 94	8.10	2640 00	1 25	4.376	300 00	11 00	45 00	55 00	590 00	235 00	41 00	31 00	1 28
Blackmans Lagoon	10.3 94	7 90	2380 00	0 45	3 512	315 00	11 00	39 00	57 00	590 00	220 00	41 00	33 00	1 49
Blackmans Lagoon	6 4 94	8 10	2430 00	0 25	4 721	405 00	14 00	48 00	75 00	700 00	260 00	36 00	35 20	0 64
Blackmans Lagoon	5 5 94	8 09	2640 00	0 95	4 894	385 00	15 00	49 00	69 00	725 00	255 00	49 00	35 50	12.26
Blackmans Lagoon	2 6 94	8 18	2560 00	0 20	3 455	365 00	13 00	47 00	67 00	725 00	250 00	48 00	32 30	1 81
Blackmans Lagoon	29 6 94	8 25	2570 00	1 00	3 515	366 00	14 00	54 00	70 00	659 00	105 00	43 00	32 30	
Blackmans Lagoon	28 7 94	8 22	2180 00	1 00	3 224	369 00	14 00	52 00	70 00	640 00	110 00	34 00	44 00	0 80
Blackmans Lagoon	1 9 94	8 28	2590 00	0 90	3 627	395 00	15 00	52 00	71 00	610 00	110 00	44 00	43 00	2 80
Blackmans Lagoon	13 10 94	8 72	2720 00	2 40	3 686	425 00	16 00	55 00	76 00	695 00	105 00	43 00	42 00	0 80
Blackmans Lagoon	18 1 95	7 65	2820 00	0 65	3 910	485 00	26 50	48 00	86 00	850 00	8 70	310 00	37 00	1 07
Bowlers No 1	24 11 93	8 20	892 00	0 20	4 203	155 00	5 40	28 00	24 00	280 00	185 00	2 40	19 00	4 27
Bowlers No 1	18 12 93	6 40	1140 00	0 14	4 030	195 00	6 70	33 00	38 00	320 00	190 00	13 00	10 00	0 61
Bowlers No 1	10 1 94	7 20	575 00	0 35	4 318	135 00	5 40	44 00	34 00	230 00	195 00	11 00	17 00	0 21
Bowlers No 1	9 2 94	7 40	1472 00	1 50	10 997	115 00	4 90	40 00	28 00	200 00	205 00	2 50	37 00	0 58
Bowlers No 1	10 3 94	6 60	1260 00	0 70	3 570	225 00	8 20	14 00	28 00	445 00	12 00	33 00	18 00	3 20
Bowlers No 1	6 4 94	7 10	1329 00	0 45	3 684	170 00	10 00	57 00	38 00	265 00	300 00	0 70	21 60	4.37
Bowlers No 1	4 5 94	6 75	2520 00	10 00	2 936	160 00	7 50	69 00	37 00	260 00	330 00	1 60	17 50	0 85
Bowlers No 1	3 6 94	7 67	1570 00	2 00	4 261	165 00	8 40	56 00	38 00	300 00	305 00	4 10	19 50	1 81
Bowlers No 1	30 6 94	8 53	1447 00	0 25	3 973	170 00	7 50	59 00	38 00	293 00	115 00	3 70	18 30	
Bowlers No 1	27 7 94	6 82	1180 00	4 50	3 109	169 00	9 90	44 00	38 00	290 00	105 00	4 20	22 00	
Bowlers No 1	1 9 94	7 64	1362 00	3 00	3 397	170 00	7 10	56 00	37 00	270 00	110 00	0 50	23 50	0 93
Bowlers No 1	13 10 94	7 79	1390 00	0 40	3 224	185 00	7 60	45 00	40 00	280 00	100 00	0 05	42 00	0 27
Bowlers No 1	18 1 95	7 21	1415 00	6 00	4 500	220 00	15 50	60 00	43 00	320 00	5 70	334 00	18 60	11 73
Cape Naturaliste No 1	25 11 93	5 70	709 00	0 12	19 979	125 00	3 50	4 80	15 00	240 00	12 00	21 00	22 00	0 98
Cape Naturaliste No 1	18 12 93	5 40	1083 00	0 15	25 045	240 00	7 60	7 80	31 00	485 00	5 10	41 00	36 00	1 64
Cape Naturaliste No 1	10 1 94	5 40	570 00	5 50	20 785	120 00	5 00	5 30	16 00	210 00	5 70	24 00	30 00	4 69
Cape Naturaliste No 1	9 2 94	6 30	2080 00	0 70	23 721	245 00	9 00	8 80	32 00	505 00	13 00	33 00	42 00	0 21
Cape Naturaliste No 1	9 3 94	5 00	1974 00	0 10	16 466	200 00	6 80	7 50	25 00	320 00	6 20	30 00	36 00	4 05
Cape Naturaliste No 1	6 4 94	5 60	2030 00	0 25	12 782	345 00	12 00	10 00	40 00	655 00	7 50	46 00	31 50	0 75
Cape Naturaliste No 1	4 5 94	7 60	1392 00	2 50	11 515	395 00	14 00	16 00	48 00	770 00	12 00	59 00	40 80	6 08
Cape Naturaliste No 1	3 6 94	7 50	2100 00	0 41	11 285	265 00	10 00	21 00	39 00	585 00	25 00	60 00	18 60	1 71
Cape Naturaliste No 1	30 6 94	7 91	1429 00	0 70	13 012	210 00	7 50	15 00	29 00	392 00	7 10	33 00	23 80	
Cape Naturaliste No 1	27 7 94	7 12	1270 00	0 80	14 566	225 00	7 90	15 00	31 00	410 00	6 60	37 00	33 00	
Cape Naturaliste No 1	1 9 94	6 75	1242 00	2 50	54 121	195 00	6 10	12 00	24 00	330 00	4 50	30 00	37 00	1 07
Cape Naturaliste No 1	13 10 94	7 62	1525 00	1 00	13 991	250 00	7 50	14 00	33 00	450 00	8 00	53 00	47 00	0 48
Cape Naturaliste No 1	18 1 95	7 30	1685 00	1 00	11 380	370 00	18 50	34 00	39 00	515 00	28 00	25 00	45 00	0 67
Cape Naturaliste No 2	18 12 93	5 70	482 00	0 40	42 606	120 00	5 10	7 90	16 00	320 00	190 00	13 00	23 00	2 13
Cape Naturaliste No 2	10 1 94	5 40	427 00	2 00	35 754	135 00	4 90	7 70	18 00	210 00	13 00	19 00	32 00	0 64
Cape Naturaliste No 2	9 2 94													
Cape Naturaliste No 2	9 3 94	5 90	1525 00	0 60	36 848	125 00	4 60	47 00	30 00	215 00	230 00	47 00	42 00	21 33
Little Waterhouse	23 11 93	8 70	1388 00	0 15	3 915	255 00	4 80	43 00	41 00	440 00	195 00	50 00	25 00	0 52
Little Waterhouse	17 12 93	8 80	1879 00	0 10	3 627	290 00	6 00	49 00	53 00	525 00	210 00	57 00	14 00	0 00
Little Waterhouse	10 1 94	7 70	844 00	1 00	3 973	175 00	4 10	42 00	33 00	300 00	170 00	43 00	27 00	1 92
Little Waterhouse	9 2 94	7 50	2450 00	0 90	6 448	260 00	5 00	50 00	46 00	490 00	215 00	56 00	27 00	0 85
Little Waterhouse	10 3 94	7 40	2120 00	0 25	4 548	200 00	3 60	44 00	37 00	340 00	180 00	45 00	30 00	1 81
Little Waterhouse	6 4 94	8 50	2180 00	0 15	4 030	355 00	7 60	56 00	60 00	600 00	240 00	69 00	31 50	1.39
Little Waterhouse	5 5 94	7 83	2370 00	1 50	5 124	350 00	7 90	60 00	60 00	615 00	250 00	69 00	31 40	2.45
Little Waterhouse	2 6 94	8 24	2620 00	0 15	3 915	320 00	6 30	59 00	57 00	600 00	250 00	77 00	24 90	1 17
Little Waterhouse	29 6 94	8 02	2270 00	1 50	3 570	314 00	8 10	71 00	59 00	550 00	105 00	73 00	30 60	
Little Waterhouse	28 7 94	8 08	1960 00	0 45	3 512	313 00	7 90	75 00	59 00	530 00	115 00	85 00	35 00	
Little Waterhouse	1 9 94	8 03	2300 00	4 00	3.339	325 00	8 80	72 00	59 00	490 00	100 00	86 00	39 00	0 40
Little Waterhouse	13 10 94	8 84	2330 00	0 25	3 627	340 00	8 60	67 00	59 00	595 00	93 00	81 00	35 00	0 48
Little Waterhouse	18 1 95	7 76	2350 00	0 50	4 830	430 00	16 50	55 00	82 00	690 00	47 00	220 00	34 00	1 73
Little Waterhouse	3 2 95	8 10	2340 00	1 50	0 806	450 00	18 00	55 00	79 00	655 00	27 00	225 00	34 00	0 67

major ions and DOC are expressed in mg/l
:h "a" is in μ

APPENDIX 5 NE Tasmanian Dune Lakes Physicochemical Data (Nov 93-Oct 94)
Temperature Oxygen

Site	Date	Temp (Z=10cm)	Temp (Z=50cm)	DO2 ppm (50cm)	DO2 % (50cm)	DO2 ppm (10cm)	DO2 % 10cm (10cm)
Blackmans Lagoon	25.11 93	19 2	19 2	11 0	100 0	11 5	126
Big Waterhouse	23 11 93	20 9	20 9	8 8	98.0		
Little Waterhouse	23 11 93	21 2	16.5	8 8	96.0		
Cape Naturaliste No.1	25 11 93	21 3	16.6	5 4	57 0	7 6	83
Bowlers No.1	24 11 93	16.2	14 8	0 3	2.0	4.5	44
Blackmans Lagoon	17 12.93	17 5	20 8				
Big Waterhouse	17 12.93	21 7	20 2				
Little Waterhouse	17 12.93	20 5	18.6				
Bowlers No 1	18.12.93	18.0	16 4				
Cape Naturaliste No.1	18.12.93	26.2	21 5				
Cape Naturaliste No.2	18.12.93	29 8	22.2				
Blackmans Lagoon	9 1 94						
Big Waterhouse	9 1 94	16.1	20 5				
Little Waterhouse	10 1 94	16.2	15.0				
Bowlers No.1	10 1 94	15 8	15 0				
Cape Naturaliste No.1	10 1 94	15.6	14 3				
Cape Naturaliste No.2	10 1 94	14 8	14 8				
Blackmans Lagoon	9 2.94		23.6	8 6	98.0		
Big Waterhouse	9 2.94	24 0	23 3	7 2	83 0	9 3	102
Little Waterhouse	9 2.94	23 9	22.2	4 9	54 0	6 7	79
Bowlers No.1	9 2.94	20 1	19 3	0 0	0 0	1 5	21
Cape Naturaliste No.1	9 2.94	22.6	19 9	2 2	25.0	5 4	56
Blackmans Lagoon	10 3 94	18.7	18.4				
Big Waterhouse	10 3 94	18.1	17 7				
Little Waterhouse	10 3 94	18 3	17 8				
Bowlers No.1	10 3 94	17 6	17 1				
Cape Naturaliste No.1	9 3 94						
Blackmans Lagoon	6 4 94	17 8	17 8				
Big Waterhouse	6 4 94	17 8	17 4				
Little Waterhouse	6 4 94	18.1	17 8				
Cape Naturaliste No.1	6 4 94	18.1	18.1				
Bowlers No.1	6 4 94	16.1					
Blackmans Lagoon	5 5 94	13 9	12.9	11 7	93 0		
Big Waterhouse	5 5 94	15 4	15 5	10 2	92.0		
Little Waterhouse	5 5 94	9 6	11 1	7 9	75 0	8 8	83
Cape Naturaliste No.1	4 5 94	12.8					
Bowlers No 1	4 5 94	11 4	8 6	0 5	5 0	5 1	45
Blackmans Lagoon	2 6 94	12.5	12.7	9 5	91 0		
Big Waterhouse	2.6 94	11 9	11 6	9 3	85 0		
Little Waterhouse	2 6 94	12.9	12.8	8.7	85 0		
Cape Naturaliste No.1	3 6.94	9 7					
Bowlers No 1	3 6.94	11 7	11 5				
Blackmans Lagoon	29 6 94	9 5	9 1				
Big Waterhouse	29 6 94		9 9				
Little Waterhouse	29 6 94	8.2	8 4				
Cape Naturaliste No.1	30 6 94	3 8	4 2				
Bowlers No.1	30 6 94	2 9	4 8				
Blackmans Lagoon	28.7 94		9 8				
Big Waterhouse	28.7 94		10 8				
Little Waterhouse	28.7 94		9 3				
Cape Naturaliste No.1	27 7 94		11 5				
Bowlers No.1	27 7 94		8 0				
Blackmans Lagoon	1 9 94						
Big Waterhouse	1 9 94						
Little Waterhouse	1 9 94						
Cape Naturaliste No 1	1 9 94	12.9					
Bowlers No.1	1 9 94						
Blackmans Lagoon	13 10 94		19 0				
Big Waterhouse	13 10 94	16.7	15 9				
Little Waterhouse	13 10 94	16 7	16.6				
Cape Naturaliste No.1	13 10 94	20 6	16 9	5 5	71 0		
Bowlers No 1	13 10 94		13 7	4 7	55 0		

Temperature is in Celcius
DO2 is measured as ppm and % saturation.

APPENDIX 6 NE Tasmanian Dune Lake Nutrient Data Nov 1993-Oct 1994

Site	Date	Total P	Nitrate	Nitrite
Blackmans Lagoon	25 11 93	0 05	<0 1	<0 01
Big Waterhouse	23 11 93	0 03	<0 1	0 05
Little Waterhouse	23 11 93	0 05	<0 1	<0 01
Cape Naturaliste No 1	25.11 93	0 04	<0 1	<0 01
Bowlers No 1	24 11 93	0 01	<0 1	<0 01
Blackmans Lagoon	17 12 93	0 04	<0 1	<0 01
Big Waterhouse	17 12 93	0 03	<0 1	<0 01
Little Waterhouse	17 12 93	0 03	<0 1	<0 01
Bowlers No 1	18.12 93	0 01	<0 1	<0 01
Cape Naturaliste No 1	18.12 93	0 06	<0 1	<0 01
Cape Naturaliste No 2	18.12 93	0 05	<0 1	0 02
Blackmans Lagoon	9 1 94	0 05	<0 1	0 01
Big Waterhouse	9 1 94	0 02	19	<0 01
Little Waterhouse	10 1 94	0 02	<0 1	<0 01
Bowlers No 1	10 1 94	0 02	<0 1	<0 01
Cape Naturaliste No 1	10 1 94	0 07	<0 1	<0 01
Cape Naturaliste No 2	10.1 94	0 06	<0 1	<0 01
Blackmans Lagoon	9 2 94	0 04	<0 1	<0 01
Big Waterhouse	9 2 94	0 03	<0 1	<0 01
Little Waterhouse	9 2 94	0 06	<0 1	<0 01
Bowlers No 1	9 2 94	0 16	<0 1	<0 01
Cape Naturaliste No 1	9 2 94	0 02	<0 1	<0 01
Blackmans Lagoon	10 3 94	0 03	<0 1	<0 01
Big Waterhouse	10 3 94	0 03	<0 1	<0 01
Little Waterhouse	10 3 94	0 03	<0 1	<0 01
Bowlers No 1	10 3 94	0 03	<0 1	<0 01
Cape Naturaliste No 1	9 3 94	0 06	<0 1	<0 01
Cape Naturaliste No 2	9 3 94	0 14	<0 1	<0 01
Blackmans Lagoon	6 4 94	0 02	<0 1	<0 01
Big Waterhouse	6 4 94	0 02	<0 1	<0 01
Little Waterhouse	6 4 94	0 03	<0 1	<0 01
Cape Naturaliste No 1	6 4 94	0 01	<0 1	<0 01
Bowlers No 1	6 4 94	0 03	<0 1	<0 01
Blackmans Lagoon	5 5 94	0 028	<0 1	<0 01
Big Waterhouse	5 5 94	0 025	<0 1	<0 01
Little Waterhouse	5 5 94	0 013	<0 1	<0 01
Cape Naturaliste No 1	4 5 94	0 075	<0 1	<0 01
Bowlers No 1	4 5 94	0 175	<0 1	<0 01
Blackmans Lagoon	2 6 94	0 017	0 2	0 02
Big Waterhouse	2 6 94	0 087	0 1	<0 01
Little Waterhouse	2 6 94	0 021	0 2	<0 01
Cape Naturaliste No 1	3 6 94	0 032	0 1	<0 01
Bowlers No 1	3 6 94	0 015	0 1	<0 01
Blackmans Lagoon	29 6 94	0 018	<0 1	<0 01
Big Waterhouse	29 6 94	0 029	<0 1	<0 01
Little Waterhouse	29 6 94	0 064	<0 1	<0 01
Cape Naturaliste No 1	30 6 94	0 041	<0 1	<0 01
Bowlers No 1	30 6 94	0 049	<0 1	<0 01
Blackmans Lagoon	28 7 94	0 02	<0 1	<0 01
Big Waterhouse	28 7 94	0 024	<0 1	<0 01
Little Waterhouse	28 7 94	0 016	<0 1	<0 01
Cape Naturaliste No 1	27 7 94	0 027	<0 1	<0 01
Bowlers No 1	27 7 94	0 102	<0 1	<0 01
Blackmans Lagoon	1 9 94	0 013	<0 1	<0 01
Big Waterhouse	1 9 94	0 012	<0 1	<0 01
Little Waterhouse	1 9 94	0 02	<0 1	<0 01
Cape Naturaliste No 1	1 9 94	0 02	<0 1	<0 01
Bowlers No 1	1 9 94	0 034	<0 1	<0 01
Blackmans Lagoon	13 10 94	0 032	<0 1	<0 01
Big Waterhouse	13 10 94	0 009	<0 1	<0 01
Little Waterhouse	13 10 94	0 013	<0 1	<0 01
Cape Naturaliste No 1	13 10 94	0 016	<0 1	<0 01
Bowlers No 1	13 10 94	0 094	<0 1	<0 01

All measurements are in mg/l

APPENDIX 7 Cape Naturaliste No1 Fauna sampled Nov 1993 - Oct 1994

Date	25.11 93	17.12.93	10 1.94	9.2.94	9.3.94	6.4 94	5.5.94	2 6.94	30.6.94	27 7.94	1 9.94	13.10 94
CRUSTACEA												
Amphipoda												
Austrochiltonia spp.	*	*	*	*	*	*	*	*	*	*	*	*
Paracallhope sp		*										
Copepoda												
Harpacticoida												
Canthocamptus spp.	*			*				*	*	*		*
Canthocamptus henryae.							*					
Schizopera sp							*					
Calanoida												
Boeckella sp.	*	*	*	*	*	*	*			*	*	*
Boeckella nyoraensis									*			*
Boeckella propinqua.										*		
Calamoecia austr alis	*	*	*	*	*	*	*				*	*
Calamoecia gibbosa gil	*				*	*		*		*	*	
Hemiboeckell searli						*					*	*
Cyclopoida	*	*	*	*		*	*	*	*	*		*
Cladocera												
Bosminidae												
Bosmina meridionalis								*				
Chydoridae												
Alona spp	*	*		*	*		*	*		*	*	*
Alonella spp.		*		*		*	*	*	*			*
Archepleuroxus baylii				*								
Biapertura spp.						*	*		*			
Biapertura cf setigera				*	*		*					
Camptocercus australis	*	*		*		*	*		*	*	*	*
Chydorus spp	*	*	*	*		*	*	*	*	*		*
Durihevedia crassa								*	*			
Ephemeroporus sp		*		*	*	*	*					*
Graptoleberis testudinaria		*				*		*	*			
Pleuroxus sp	*	*									*	
Rak sp	*	*		*	*		*		*	*		
Daphnidae												
Ceriodaphnia sp.		*		*				*	*			
Simochepalus sp.	*	*	*	*	*	*	*		*	*	*	*
Ilyocryptidae												
Ilyocryptus sp.	*	*	*	*		*	*			*	*	*
Macrothricidae												
Macrothrix spp	*		*	*			*	*	*			*
Macrothrix cf. armata	*	*										
Macrothrix cf longisetosa						*			*			
Macrothrix cf. pectinatus						*	*					
Ostrocoda												
Cypretta sp.		*	*	*		*		*	*	*	*	*
Gomphodella sp.		*		*			*		*	*	*	*
Ilyodromus cf candonites		*	*	*		*		*		*		*
Kervuelua crystata				*			*	*	*	*		*
Limnocythere cf. mowbrayensis		*	*				*	*				*
Newnhamia sp		*	*	*		*	*	*	*	*	*	*

APPENDIX 8 Little Waterhouse Faunal Species list Nov 1993 - Oct 1994

Date	23 11 93	17 12 93	9 1 94	9 2 94	6 4 94	5 5 94	2 6 94	29 6 94	28 7 94	1 9 94	13 10 94
CRUSTACEA											
Amphipoda											
Austrochiltonia spp.	*	*	*	*	*	*	*	*	*	*	*
Copepoda											
Harpacticoida											
Canthocamptus australicus							*			*	
Canthocamptus henryae	*			*	*	*	*	*	*	*	*
Schizopera sp.	*				*				*		
Calanoida											
Boeckella symmetrica	*	*	*	*	*	*	*	*	*	*	*
Calamoecia austr alis										*	
Calamoecia gibbosa gibbosa										*	
Gladioferens spinosus		*									
Cyclopoida	*	*	*	*	*	*	*	*	*	*	*
Cladocera											
Bosminidae											
Bosmina meridionalis							*				
Chydoridae											
Alona spp.	*	*	*	*		*	*	*	*	*	*
Alona diaphana	*					*	*				
Alonella sp.		*	*	*		*	*	*	*	*	*
Biapertura cf affinis							*				
Biapertura cf longiqua											
Biapertura rigidicaudis						*	*				
Biapertura cf setigera						*	*			*	
Camptocercus australis	*	*		*		*	*	*		*	*
Chydorus sp.	*	*	*	*		*	*	*	*	*	*
Dunhevedia crassa	*	*	*	*		*	*			*	*
Ephemeroporus sp.											
Graptoleberis testudina	*	*		*		*	*	*		*	*
Kurzia sp.							*				
Pleuroxus sp.			*	*						*	
Pseudochydorus globulosus						*	*		*	*	
Rak sp						*					
Daphnidae											
Ceriodaphnia sp	*	*	*	*	*	*		*			
Simochepalus sp	*	*	*	*		*	*	*	*	*	*
Daphnia sp									*		*
Macrothricidae											
Macrothrix sp.							*				
Ostrocoda											
Cypretta spp		*		*		*	*			*	
Gomphodella sp.		*		*		*		*		*	
Ilyodromus cf cardonite	*	*	*	*		*	*	*		*	
Kennethia cristata	*	*	*	*	*	*	*	*	*	*	*
Limnocythere mowbrayensis		*	*		*	*	*	*		*	*
Newnhamia sp		*									

APPENDIX 9 Blackmans Lagoon Fauna Sampled Nov 1993 - Oct 1994

Date	25.11.93	17.12 93	9.1.94	10.2.94	6.4 94	5.5.94	2.6.94	29.6.94	28.7 94	1.9.94	13.10.94
CRUSTACEA											
Amphipoda											
Austrochiltonia spp.	*	*	*	*	*	*		*	*	*	*
Copepoda											
Harpacticoida											
Canthocamptus australicus	*										
Canthocamptus henryae								*			
Schizopera sp.	*			*					*		
Calanoida											
Boeckella symmetrica	*	*	*	*	*	*	*	*	*	*	*
Gladioferens spinosus										*	
Cyclopoida					*	*					
Cladocera											
Chydoridae											
Alona sp.	*					*	*				
Alona diaphana				*							
Alonella spp.						*	*				
Biapertura cf setigera					*						
Camptocercus australis						*					
Chydorus spp.	*	*	*	*	*	*	*	*	*	*	
Dunhevedia crassa						*			*		
Graptoleberis testudinaria						*	*				
Pleuroxus sp.			*	*	*	*					
Daphnidae											
Ceriodaphnia sp.		*	*	*	*	*		*			
Simocephalus sp.	*					*					
Daphnia sp.	*	*	*	*					*		*
Ostrocoda											
Gomphodella sp.								*			
Ilyodromus cf candonites								*			
Kennethia cristata	*	*	*	*	*	*	*	*	*	*	*
Limnocythere mowbrayensis				*							
Macrothricidae											
Macrothrix sp.					*	*					

APPENDIX 10 Big Waterhouse Lake Faunal species list Nov 1993-Oct. 1994

Date	23 11.93	9.2 94	6 4 94	5 5 94	2 6 94	29 6.94	28.7.94	1 9 94	13.10 94
Crustacea									
Amphipoda									
Austrochiltonia spp.	*		*	*	*	*	*	*	
Paracalliope sp.			*	*	*	*			
Copepoda									
Harpacticoida									
Camptocercus henryae	*		*		*			*	*
Calanoida									
Boeckella sp.				*	*				
Gladioferens spinosus	*		*	*	*	*	*	*	*
Cyclopoida	*		*	*	*	*	*	*	
Cladocera									
Bosminidae									
Bosmina meridionalis				*	*				
Chydoridae									
Alona sp									*
Alonella sp.	*		*		*	*	*	*	
Biapertura cf affinis	*		*				*		
Biapertura cf. longiqua	*								
Camptocercus australis					*	*	*	*	
Chydorus sp.	*		*		*	*	*	*	
Dunhevedia crassa				*		*	*		
Ephemeroporus sp.				*				*	
Graptoleberis testudinaria	*		*		*	*	*	*	
Pleuroxus sp.			*						
Pseudochydorus globosus			*		*	*	*		
Rak sp.								*	
Daphnidae									
Ceriodaphnia sp			*	*		*			
Simocephalus sp	*		*	*	*	*	*	*	
Macrothricidae									
Macrothrix spp			*	*					
Ostrocoda									
Cypretta sp					*				
Kennethia cristata	*		*	*	*	*	*	*	*

Appendix 11 Bowlers Lagoon Fauna sampled Nov 1993- Oct 1994

Date	24.11.93	10.1.94	6.4.94	5.5.94	2.6.94	30.6.94	28.7.94	1.9.94	12 10.94
CRUSTACEA									
Amphipoda									
Austrochiltonia spp									*
Copepoda									
Harpacticoida									
Canthocamptus henryae	*	*	*	*	*	*	*	*	*
Cyclopoida									*
Cladocera									
Chydoridae									
Alona sp.	*				*			*	
Alona diaphana		*							
Alonella sp.	*	*		*	*	*	*	*	
Biapertura spp.	*								
Biapertura cf affinis						*	*		
Biapertura rigidicaudis		*					*		
Biapertura cf setigera	*				*			*	
Camptocercus australis	*	*			*	*	*	*	*
Chydorus sp.		*		*	*	*		*	
Dunhevedia crassa		*			*	*	*	*	
Ephemeroporus sp.	*	*							
Graptoleberis testudinaria		*			*		*	*	
Pleuroxus sp.	*					*	*	*	
Pseudochydorus globulosus					*				
Daphniidae									
Simochepalus sp.					*	*		*	

AVERAGE DISSIMILARITY BETWEEN GROUPS 2 & 1 IS 76.92%						
	Group 2	Group 1				
SPECIES	av abundance	av abundance	TERM	RATIO	%	cum %
Canthocamptus henryae	0.08	1.00	4.04	2.44	5.26	5.26
Austrochiltonia spp.	1.00	0.11	3.79	2.21	4.93	10.18
Boeckella sp.	0.83	0.00	3.66	1.84	4.75	14.94
Newnhamia sp.	0.83	0.00	3.41	1.97	4.43	19.37
Calamoecia australis	0.75	0.00	3.30	1.49	4.30	23.66
Cypretta sp.	0.75	0.00	3.12	1.58	4.05	27.71
Ilyocryptus sp.	0.75	0.00	3.11	1.57	4.05	31.76
Cyclopoida	0.83	0.11	3.07	1.61	3.99	35.76
Simocephalus sp.	0.92	0.33	2.91	1.20	3.78	39.53
Alona spp.	0.75	0.33	2.60	1.08	3.38	42.92
Rak sp.	0.58	0.00	2.48	1.07	3.22	46.14
Macrothrix spp.	0.58	0.00	2.40	1.12	3.12	49.25
Calamoecia gibbosa	0.50	0.00	2.39	0.94	3.10	52.36
AVERAGE DISSIMILARITY BETWEEN GROUP 3 & 1 is 62.34%						
	Group 3	Group 1				
SPECIES	av abundance	av abundance	TERM	RATIO	%	cum %
Boeckella symmetrica	1.00	0.00	4.56	3.49	7.32	7.32
Kennethia cristata	1.00	0.11	4.01	2.12	6.44	13.76
Cyclopoida	1.00	0.11	3.98	2.14	6.39	20.15
Austrochiltonia spp.	1.00	0.11	3.98	2.14	6.39	26.54
Limnocythere mowbrayensis	0.73	0.11	3.03	1.26	4.86	31.40
Ceriodaphnia sp.	0.64	0.00	3.01	1.19	4.84	36.24
Ilyodromus cf candonites	0.73	0.00	2.99	1.51	4.80	41.04
Simocephalus sp.	0.91	0.33	2.93	1.23	4.71	45.75
Alona spp.	0.91	0.33	2.93	1.23	4.71	50.45
AVERAGE DISSIMILARITY BETWEEN GROUP 3 & 2 is 53.88%						
	Group 3	Group 2				
SPECIES	av abundance	av abundance	TERM	RATIO	%	cum %
Boeckella symmetrica	1.00	0.00	3.08	4.78	5.72	5.72
Boeckella sp.	0.00	0.83	2.59	1.97	4.80	10.52
Canthocamptus henryae	0.82	0.08	2.38	1.64	4.41	14.93
Newnhamia sp.	0.09	0.83	2.31	1.71	4.29	19.22
Ilyocryptus sp.	0.00	0.75	2.25	1.61	4.17	23.39
Calamoecia australis	0.09	0.75	2.21	1.42	4.11	27.50
Dunhevedia crassa	0.73	0.17	1.92	1.30	3.57	31.07
Graptoleberis testudinaria	0.73	0.33	1.74	1.12	3.23	34.30
Rak sp.	0.09	0.58	1.73	1.08	3.22	37.52
Ceriodaphnia sp.	0.64	0.33	1.73	1.04	3.21	40.73
Macrothrix spp.	0.09	0.58	1.71	1.10	3.17	43.89
Cypretta sp.	0.45	0.75	1.68	1.01	3.12	47.01
Limnocythere mowbrayensis	0.73	0.42	1.68	1.03	3.11	50.12

Group 1 = Bowlers Lagoon
Group 2 = Cape Naturaliste
Group 3 = Little Waterhouse
Group 3 = Big Waterhouse
Group 5 = Blackmans Lagoon

AVERAGE DISSIMILARITY BETWEEN GROUP 4 & 1 is 71.67%						
	Group 4	Group 1				
SPECIES	av abundance	av abundance	TERM	RATIO	%	cum %
Canthocamptus henryae	0.00	1.00	6.11	2.09	8.53	8.53
Gladioferens spinosus	1.00	0.00	6.11	2.09	8.53	17.06
Kennethia cristata	1.00	0.11	5.37	1.58	7.50	24.56
Austrochiltonia spp.	0.88	0.11	4.28	1.63	5.98	30.54
Cyclopoida	0.88	0.11	4.28	1.63	5.98	36.52
Simocephalus sp.	0.88	0.33	3.67	1.21	5.12	41.64
Graptoleberis testudinaria	0.75	0.44	3.17	1.00	4.43	46.07
Camptocercus australis	0.50	0.78	3.11	0.90	4.34	50.41
AVERAGE DISSIMILARITY BETWEEN GROUP 4 & 2 is 62.45%						
	Group 4	Group 2				
SPECIES	av abundance	av abundance	TERM	RATIO	%	cum %
Gladioferens spinosus	1.00	0.00	3.67	4.06	5.88	5.88
Newnhamia sp.	0.00	0.83	2.92	1.99	4.67	10.55
Calamoecia australis	0.00	0.75	2.79	1.52	4.47	15.02
Ilyocryptus sp.	0.00	0.75	2.66	1.58	4.26	19.28
Boeckella sp.	0.25	0.83	2.52	1.28	4.03	23.31
Cypretta sp.	0.13	0.75	2.48	1.38	3.96	27.28
Alona spp.	0.13	0.75	2.42	1.38	3.88	31.16
Graptoleberis testudinaria	0.75	0.33	2.12	1.13	3.39	34.55
Rak sp.	0.13	0.58	2.04	1.05	3.26	37.81
Ilyodromus cf candonites	0.00	0.58	2.03	1.12	3.25	41.06
Kennethia cristata	1.00	0.50	2.02	0.93	3.23	44.29
Calamoecia gibbosa	0.00	0.50	2.00	0.94	3.19	47.48
Gomphodella sp.	0.00	0.58	1.96	1.13	3.14	50.63
AVERAGE DISSIMILARITY BETWEEN GROUP 4 & 3 is 51.81%						
	Group 4	Group 3				
SPECIES	av abundance	av abundance	TERM	RATIO	%	cum %
Boeckella symmetrica	0.00	1.00	3.83	3.78	7.40	7.40
Gladioferens spinosus	1.00	0.09	3.52	2.35	6.79	14.18
Canthocamptus henryae	0.00	0.82	3.13	1.77	6.04	20.22
Alona spp.	0.13	0.91	2.86	1.80	5.51	25.74
Limnocythere mowbrayensis	0.00	0.73	2.74	1.42	5.30	31.03
Ilyodromus cf candonites	0.00	0.73	2.56	1.51	4.94	35.98
Ceriodaphnia sp.	0.38	0.64	2.11	0.98	4.08	40.05
Dunhevedia crassa	0.38	0.73	2.10	1.06	4.05	44.11
Camptocercus australis	0.50	0.73	1.94	0.95	3.74	47.84
Pseudochydorus globulosus	0.50	0.36	1.83	0.96	3.54	51.38
AVERAGE DISSIMILARITY BETWEEN GROUP 5 & 1 is 80.99%						
	Group 5	Group 1				
SPECIES	av abundance	av abundance	TERM	RATIO	%	cum %
Boeckella symmetrica	1.00	0.00	7.42	2.82	9.16	9.16
Canthocamptus henryae	0.09	1.00	6.78	2.02	8.38	17.53

Group 1 = Bowers Lagoon
Group 2 = Cape Naturaliste
Group 3 = Little Waterhouse
Group 3 = Big Waterhouse
Group 5 = Blackmans Lagoon

Kennethia cristata	1.00	0.11	6.51	1.89	8.04	25.57
Austrochiltonia spp.	0.91	0.11	5.88	1.60	7.26	32.83
Camptocercus australis	0.00	0.78	5.13	1.68	6.33	39.16
Alonella sp.	0.18	0.78	4.59	1.34	5.67	44.83
Daphnia sp.	0.55	0.00	4.18	0.97	5.16	49.99
Chydorus spp.	0.91	0.56	3.75	0.83	4.63	54.62

Group 1 = Bowlers Lagoon
Group 2 = Cape Naturaliste
Group 3 = Little Waterhouse
Group 3 = Big Waterhouse
Group 5 = Blackmans Lagoon

AVERAGE DISSIMILARITY BETWEEN GROUP 5 & 2 is 73.2%						
	Group 5	Group 2				
SPECIES	av abundance	av abundance	TERM	RATIO	%	cum %
Boeckella symmetrica	1.00	0.00	4.17	4.41	5.69	5.69
Boeckella sp.	0.00	0.83	3.51	1.92	4.80	10.49
Newnhamia sp.	0.00	0.83	3.29	2.03	4.49	14.99
Simocephalus sp.	0.18	0.92	3.28	1.63	4.49	19.47
Calamoecia australis	0.09	0.75	3.02	1.40	4.13	23.60
Cypretta sp.	0.00	0.75	3.01	1.62	4.11	27.70
Ilyocryptus sp.	0.00	0.75	3.00	1.61	4.10	31.81
Camptocercus australis	0.00	0.75	2.89	1.64	3.95	35.75
Cyclopoida	0.18	0.83	2.87	1.50	3.93	39.68
Alona spp.	0.27	0.75	2.59	1.18	3.54	43.22
Rak sp.	0.00	0.58	2.38	1.10	3.26	46.48
Daphnia sp.	0.55	0.00	2.32	1.04	3.17	49.64
Kennethia cristata	1.00	0.50	2.32	0.95	3.16	52.81

AVERAGE DISSIMILARITY BETWEEN GROUP 5 & 3 is 52.28%						
	Group 5	Group 3				
SPECIES	av abundance	av abundance	TERM	RATIO	%	cum %
Cyclopoida	0.18	1.00	3.70	1.85	7.07	7.07
Canthocamptus henryae	0.09	0.82	3.33	1.57	6.36	13.43
Simocephalus sp.	0.18	0.91	3.28	1.66	6.27	19.70
Limnocythere mowbrayensis	0.09	0.73	2.98	1.33	5.69	25.39
Alonella sp.	0.18	0.82	2.97	1.44	5.69	31.08
Alona spp.	0.27	0.91	2.97	1.39	5.68	36.75
Camptocercus australis	0.00	0.73	2.87	1.55	5.48	42.24
Ilyodromus cf candonites	0.09	0.73	2.76	1.40	5.28	47.52
Dunhehevedia crassa	0.18	0.73	2.66	1.28	5.09	52.62

AVERAGE DISSIMILARITY BETWEEN GROUP 5 & 4 is 63.45%						
	Group 5	Group 4				
SPECIES	av abundance	av abundance	TERM	RATIO	%	cum %
Boeckella symmetrica	1.00	0.00	5.70	3.00	8.98	8.98
Gladioferens spinosus	0.09	1.00	5.09	2.14	8.03	17.00
Simocephalus sp.	0.18	0.88	3.95	1.61	6.22	23.23
Cyclopoida	0.18	0.88	3.95	1.61	6.22	29.45
Alonella sp.	0.18	0.75	3.49	1.31	5.50	34.95
Graptoleberis testudinaria	0.18	0.75	3.49	1.31	5.50	40.44
Daphnia sp.	0.55	0.00	3.19	0.98	5.03	45.47
Ceriodaphnia sp.	0.55	0.38	2.83	0.95	4.46	49.93
Camptocercus australis	0.00	0.50	2.52	0.98	3.97	53.90

Group 1 = Bowlers Lagoon
Group 2 = Cape Naturaliste
Group 3 = Little Waterhouse
Group 3 = Big Waterhouse
Group 5 = Blackmans Lagoon

APPENDIX 13 West Coast Dune Lakes Physicochemical Data 91-92

ite	Date	pH	K25 uS/cm	Tn (NTU)	g440 (m-1)	Na	K	Ca	Mg	Cl	HCO3	SO4	TOC	DOC
ibbs Lagoon	11 10.91	6 10	139 00	1 00	10 767	23 00	1 20	2.30	4 30	38.00	14 00	5 60	13 3	12 70
ibbs Lagoon	1 4 92		160 00											
ake Bantic	11 5 91	5 20	68.30	0 40	1 267	18 00	0 00	1 60	2 50	34 00	6 00	3 70	0 0	0 00
ake Bantic	14 6 91	5 70	93 00	0 35	0 230	18 00	0.53	0 76	2 20	30 00	5 00	3 50	0 0	0 00
ake Bantic	5 9 91	5 70	108 00	0 35	0 921	20 00	0 49	1 10	2 40	31 00	2 80	4 00	9 7	11 20
ake Bantic	1 4 92	5.10	122 00	0 50	0 115	18 00	0 57	0 83	2 10	30 00	7 10	3 20		
ake Bantic	16 6 92	5 20	110 10	0 27	1 382	17 00	0 51	0.72	1 90	28 00	4 40	3 10		6 70
ake Bantic	9.9 92	5 80	138 00	0 25	1 267	16 00	0 55	0 72	2 10	27 00	3 00	3 00		5 60
ake Bantic	31 1 93	4 80	106 00	0 45	1 036	14.00	0 55	0 68	1 90	26 00	2 30	2 70		
ake Bantic	8 6 93	5 40	138 00	0 35	0 518	14 00	0 37	1.00	1 70	22 00	1 40	5 50		1 13
ake Bantic	8 11 94	5.88	112 00	0 50	0 000	16.00	0 51	1 00	2 40	24 00	1 50	3 80		1 13
ake Cumberland	3 2.93	4 20	47 90	1 50	10 997	6 40	0 49	0 26	0 70	11 00	0 70	1 20		
ake Cumberland	8 11.94	4 71	73.00	0 50	2 994	9.30	0 46	0 50	2 00	12 00	4 30	0 00		11 00
ake Garcia	11 5 91	4 50	69 80	0 30	6 045	14 00	0 41	1 50	1 80	29 00	5 00	3.10	6.0	7 20
ake Garcia	14 6 91	5 70	82 50	0 45	5 009	18 00	0 44	5 40	2 00	29 00	7 80	10 00		9 90
ake Garcia	5 9 91	4 50	118 00	0.40	8 867	18 00	0 62	0 92	2 10	29 00	5 90	3 20	0 0	2 40
ake Garcia	2 4 92	4 40	121 10	0 50	4 203	19 00	0 57	0 81	2 10	31 00	5 30	3 50	6 5	7 10
ake Garcia	16 6 92	4.50	113 70	0 40	6 448	18 00	0 44	0 75	2 00	28 00	1 00	3 30	6 7	7 90
ake Garcia	9 9 92	4 30	136 00	1 00	6 618	17 00	0 49	0 78	1 90	28 00	0 00	2 50		24 00
ake Garcia	4 2 93	4 70	105 00	1 00	10 421	17 00	0.64	0 78	2 00	29.00	0 80	2 80		
ake Garcia	8 6 93	4.60	146 00	0 30	6.276	17 00	0 46	1 00	2 30	28 00	4 80	0 00		12 60
ake Garcia	8 11 94	5 56	97 00	0 50	3 915	18 00	0 42	1 10	2 80	28 00	4 90	1 70		12 90
ake Koonya	2 2.93	3 80	107 00	1 00	28 555	16 00	0.38	0 56	1 80	26 00	0 00	4 70		
ake Koonya	20 6 92	3 70	122 00	0 52	27 866									
Lake Mallana	12 6 91	3 50	121 00	0 60	19.576	22 00	0 73	0 94	3 00	34 00	0 00	6 90	19.5	19 50
ake Mallana	5 9 91	3 90	134 00	0 60	22 166	20 00	0 77	1 10	2 50	33 00	0 00	5 40	19 9	20 50
Lake Mallana	10 10 91	3 80	136 20	0 80	22 512								19 4	20 30
Lake Mallana	20 6 92	3 90	113 00	0 63	23 721	19 00	0 75	0 80	2 40	30 00	0 00	6 00	23.7	22 40
Lake Mallana	9 9.92	4 10	146 00	0 75	15 142	16 00	0 89	0 70	2 10	28 00	0 00	4.70		24 00
Lake Mallana	8 6 93	3.90	167 00	0 85	23 030	17 00	0 69	0 60	4 30	18 00	9 00	0 00		16 00
Lake Strahan	11 5 91	4 70	189 00	0 65	8 233	36 00	0 99	1 10	5 00	66 00	3 00	8 00		13 00
Lake Strahan	12 6 91	5 10	179 00	0 40	10 651	40 00	1 10	1 20	5 00	69 00	4 80	8 70	11 0	9 80
ake Strahan	5 9 91	4 40	218 00	0 25	17 560	37 00	0 86	1 10	4 50	55 00	0 70	7 70	18 0	14 40
ake Strahan	10 10 91	4 10	225 00	0 60	21 245	36 00	0 94	1 20	4 20	56 00	1 30	7 20	18 7	16 30
ake Strahan	31 3 92	4 40	1364 00	1 00	6 909	48 00	1 40	1 10	5 80	82 00	2 00	11 20	7 8	7 20
Lake Strahan	21 6 92	4 60	230 00	0 50	17 273	36 00	0.87	1 10	4 50	60 00	1 70	8 60		60 00
Lake Strahan	9 9 92	4 70	327 00	1 00	50 493	56 00	1 20	1 40	6 00	69 00	0 90	9 90		23 00
Lake Strahan	30 1 93	4 20	262 00	0 45	24 060	36 00	1 30	1 00	4 90	72 00	1 00	8 00		
Lake Strahan	8 6 93	4 90	304 00	0 25	11 112	31 00	1 10	1 20	4 90	65 00	5 20	2 70		12 30
New Lagoon	12 6 91	3 70	186 00	0 40	29 536	36 00	0 35	1 20	5 50	63 00	0 90	6 80	30 7	31 70
New Lagoon	9 10 91	4 00	176 00	0 50	37 711								31 1	29 30
New Lagoon	31 1 93	4 50	212 00	2 00	35 408	28 00	0 80	0 72	3 80	55 00	0 00	2 90		
Parting Creek	8 10 91	4 50	59 60	0 70	12 321	11 00	0 39	0 79	1 30	15 00	1 20	2 50	11 8	12 70
Parting Creek	31 3 92	4 50	76 00	0 50	7 542	11 00	0 36	1 10	1 60	19 00	1 70	2 10	11 5	11 10
Parting Creek	20 6 92	4 10	60 00	0 63	14 048	9 20	0 29	0 84	1 30	13 00	0 00	2 40	17 8	16 90
Parting Creek	3 2 93	4.60	54 70	0 70	16 121	7 30	0 32	0 88	1 30	13 00	1 80	1 80		
Parting Creek	8 6 93	4 40	84 00	0 50	12 091	8 80	0 23	1 00	1 80	17 00	6 90	0 00		17 90
Parting Creek	8 11 94	5 95	63 80	0 50	5 670	8 80	0 23	1 20	1 40	16 00	3 90	2 80		12 20
South Strahan 1	11 10 91	4 10	281 00	0 40	42 087	46 00	2 20	2 50	5 00	75 00	1 30	5 60	38 1	37 40
South Strahan 1	31 3 92	3 80	411 00	0 50	25 160	78 00	1 30	1 80	8 30	120 00	0 00	8 50	27 3	47 60
South Strahan 1	21 6 92	3 60	300 00	0 42	38 460	46 00	1 10	1 70	5 60	68 00	0 00	10 00	52 2	26 40
South Strahan 1	30 1 93	3 70	306 00	0 45	44 040	54 00	1 50	2 80	6 40	88 00	0 00	4 10		
South Strahan 2	11 10 91	4 00	245 00	0 35	42 720	40 00	1 70	2 60	4 40	62 00	0 70	6 10	38 3	37 40
South Strahan 2	31 3 92	3 50	390 00	1 50	41 915	65 00	1 80	1 20	7 80	105 00	0 00	11 00	36 0	36 70
South Strahan 2	21.6 92	3 70	270 00	0 39	42 606	42 00	1.00	1 40	5 00	64 00	0.00	7 30	52.0	50 20
South Strahan 2	30 1 93	3 50	253 00	0 40	50 263	35 00	1 20	1 90	4 00	64 00	0 00	4 10		

All major ions, DOC TOC expressed as mg/l

APPENDIX 14 West Coast Dune Lakes Fauna Data Sampled 1991-1994

L Strahan	May-91	Jun-91	Sep-91	Oct-91	Mar 92	Jun-92	Jan-93	Feb-93	Jun-93	Nov-94
C tasmanica	*	*	*	*		*	*		*	
Cyclopoids	*	*								
Amphipods	*	*				*				
Alona spp	*	*		*		*				
Alonella spp		*								
Chydorus spp		*								
Graptoleberus sp		*								
Ilyocryptus sp		*								
Scapholeberis sp						*				
L Bantic —										
C tasmanica	*	*	*		*	*	*		*	*
Cyclopoids	*								*	*
Amphipods	*									*
Scapholeberis sp	*									
Alona spp	*									*
Alonella spp										*
Chydorus spp	*								*	*
Ceriodaphnia sp		*				*	*			*
L Cumberland										
Bosmina meridionalis								*		
Cyclopoids								*		
L. Garcia										
C tasmanica	*	*			*	*		*	*	*
Cyclopoids	*								*	
Amphipods	*								*	
Scapholeberis sp	*									
Alona spp	*								*	
Chydorus sp									*	
Ceriodaphnia sp		*			*	*		*		*
L. Koonya										
C tasmanica						*		*		
Alona spp						*		*		
Camptocercus sp						*				
Chydorus spp						*				
New Lagoon										
C tasmanica		*		*			*			
Cyclopoids							*			
Amphipods				*						
Scapholeberis sp				*						
Alona spp				*			*			
Chydorus spp		*								
Pseudomona lemnae				*						
Ilyocryptus sp							*			
L Mallana										
C tasmanica			*	*		*				
Cyclopoids		*		*		*			*	
Amphipods			*	*		*				
Pseudomona lemnae		*		*		*			*	
Alona spp				*		*				
Camptocercus sp				*		*				
Chydorus spp						*				
Daphnia				*						
Ilyocryptus sp									*	
Partung Crk.										
C tasmanica				*						*
Cyclopoids				*		*		*	*	*
Amphipods										
Ilyocryptus sp				*		*			*	
Alona spp				*		*				
Chydorus sp				*		*			*	*
Ceriodaphnia sp				*				*		*
Bosmina meridionalis				*				*	*	
South Strahan No1										
C tasmanica				*	*	*	*			
Alona spp				*	*					
Alonella spp						*				
Camptocercus sp				*						
Chydorus spp						*				
Ceriodaphnia sp							*			
South Strahan No2										
C tasmanica				*	*	*	*			
Cyclopoids										
Amphipods				*	*					
Scapheloleberis sp				*						
Alonella spp				*		*				
Camptocercus sp				*		*				
Chydorus spp				*		*				
Pseudomona lemnae				*						

Shaded areas indicate not sampled on that date

APPENDIX 15 Bruny Island Physicochemical Data

Site	Date	pH	K25	Tn (NTU)	g440	Na	K	Ca	Mg	Cl	HCO3	SO4
			uS/cm			(µeq/l)	(µeq/l)	(µeq/l)	(µeq/l)	(µeq/l)	(µeq/l)	(µeq/l)
Baines Lagoon	19 9.90	*	*	*	*	12,174	396	1,300	3,536	12,691	1,521	1,271
	23.12 90	6 5	1,150	2 5	52 34	10,345	56	1,018	4,089	15,371	*	363
	24 1.92	6.9	1,240	0 9	5 82	9,130	212	850	2,549	9,589	393	1,833
Big Lagoon	2 7 77	4 8	1,684	0 4	8 43	6,152	219	314	3,770	5,350	110	4,993
	23 1 87	6.5	770	0 4	14 85	5,565	161	40	1,382	6,515	133	562
	12 10 88	*	1,286	*	10 65	*	*	*	*	*	*	*
	19 9 90	*	*	*	*	18,261	448	1,700	4,488	20,583	295	2,500
	23.12 90	6 5	1,640	2 7	18 36	26,583	588	1,667	7,436	*	*	*
	24 1 92	6 6	2,690	1 1	13 07	21,304	499	1,950	5,592	23,973	524	3,021
D'Arreys Lagoon	2 7.77	6 8	811	1 9	5 3	30,708	155	496	1,398	26,800	450	6,109
	19 9 90	4 9	*	0.5	34 6	5,000	128	825	2,549	4,930	64	2,813
	23 12 90	4 8	740	0 5	43 66	5,400	110	706	3,247	*	*	*
	24 1.92	6 8	444	5	53 66	2,783	123	415	1,110	2,479	320	1,125
Gibbs Lagoon	2 7 77	4 4	484	17	7 14	18,300	52	202	678	1,370	176	17,686
	23 1 87	4 6	1,510	*	253 33	13,174	395	740	2,631	15,060	38	1,417
	19 9 90	*	*	*	*	38696	563	4,650	16,447	41,459	0	15,417
	23 12 90	4 2	2,510	9 5	105 59	32574	456	3,520	16,283	*	*	*
Little Lagoon	19.9 90	5 7	8,900	2 75	26 72	5,217	205	575	1,563	5,359	270	1,125
	23 12 90	7 9	572	0 8	27 75	5740	169	506	2,053	1,015	*	40

Major ions are in µequ/l